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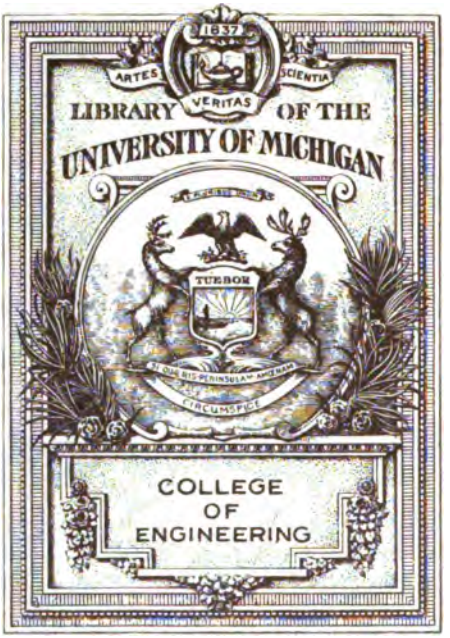
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INAUGURAL ADDRESS

BY THE PRESIDENT,

MR. E. G. CONSTANTINE,

DELIVERED SATURDAY, 17TH JANUARY, 1903.

A year ago it was my pleasant duty to thank you for the honour conferred on me by electing me your President, and the fact of your having chosen me to fill this office for a second year is a mark of your continued confidence very gratifying to me.

It is becoming increasingly difficult to find a subject for a Presidential Address which shall at once be original and interesting, and I must therefore ask your indulgence towards the few remarks which I propose to make on this occasion.

Remarkable developments and innovations are occurring in many branches of engineering science and practice, and it may therefore not be unprofitable for us to glance at

SOME PROBLEMS OF THE FUTURE.

What of electricity? Who shall foretell the limits of usefulness to which this subtle but powerful force shall be applied? Within almost the present generation we have seen the subject of electricity emerge from an abstract science into a concrete practical force, whose power is seen and felt in every department of life, to such an extent, that it has become a necessity.

The rapid development of electricity for traction purposes is known to all, and notwithstanding the comparatively recent emphatic opinions to the contrary, it will not be long before we see some of the passenger railways worked by means of electric locomotives. Who shall say how long it will be ere sparks and

smoke from railway locomotives will be a thing of the past, and evidence of the existence of steam locomotives only be found in the earlier examples preserved in the British Museum and stations of the North-Eastern Railway, and in drawings and pictures, exhibited as curiosities of the past.

The recent triumph of Marconi in exchanging messages by wireless telegraphy across the ocean, between Cornwall and Canada, need only be mentioned to show that the wildest flights of fancy in connection with electricity may one day be realised. Daily newspapers will be almost as common on the ocean liners as in our streets, and the man with overworked brain will have to take his "rest" in tramp steamers.

The only limit to the practical application of the electric current is the cost of generation, and, as in most industries in this progressive world, this is being gradually reduced. From small dynamos we have grown to large generators driven by slower-speed reciprocating engines, and the perfecting of the steam turbine is leading to the adoption of still larger units for the conversion of lines of force into electric current. We are already familiarised with the idea of 5,500 kilowatt power turbo generators.

Before electricity displaces steam in the driving of the machinery employed in the industries of this country, some means will have to be discovered whereby it can be generated at lower cost than is at present done by the heat obtained from coal, whether this be converted into portable power through the medium of the steam or gas engine.

As we have no natural waterfalls to utilize, the power stored up in the tides will have to be harnessed in our service, or the more uncertain force of the winds captured, or the energy contained in the beneficent heat from the sun impressed, and made use of. It may be thought that if this latter power is to be relied on the wheels of industry will revolve but slowly in

such districts as ours, but when this great energy is made serviceable, fogs will be ancient history and accumulators will store up power to be used as required.

He would be a rash prophet who should say that in the not distant future the illimitable forces of nature shall not be conserved and utilised for the service of man by conversion into electricity. Then will the steam engineer be at a discount, but we may take comfort to ourselves in that as we are adaptable beings, we shall be affected by the inevitable law of progress, and use our talents in the perfecting of the mechanical appliances for converting natural energy to the use of mankind.

A question of interest to engineers is whether, and if so, how long it will be before the reciprocating steam engine is supplanted by the steam turbine? One cannot think of an ideal steam turbine without being fascinated by the beauty of a motor in which the moving parts shall always be in equilibrium, practically annihilating friction and wear and tear; where the motor only requires starting and will run indefinitely as long as the steam supply is maintained, with an occasional glance over the top of his newspaper from the engineer on watch, ensconced in his arm chair on the inlaid floor of the engine room.

According to data obtained from tests made of two 1,000 kilowatt condensing turbines working with steam at 140lbs. pressure, and about 25° Fah. superheat, the steam consumption amounted to only 14·2lbs. per electric HP per hour.

With a higher steam pressure, a greater superheat, and the experience obtained in the further adoption of this form of motor, it is more than probable that for large powers the economical working of steam turbines will rival, if not surpass, that of the best design of reciprocating engines, of which it must be regarded as a formidable competitor in the future.

Whatever place the steam turbine is destined to take in the development of energy, we must all accord our meed of praise and congratulation to the Hon. C. A. Parsons, who through good and evil report, and difficulties which would have daunted most men, has for so many years laboured steadily at the problem of making the turbine a commercial success.

Before passing from the subject of steam using apparatus it would be invidious to omit a reference to that oft-times neglected and much abused patient servant, the steam boiler.

Without the fountain from whence it derives life and movement, that aggregation of parts, known as the steam engine, would be an inert mass of metal; and yet how little attention is devoted to the well being of the boiler, as compared with the efforts to lower the steam consumption of the engine a third place in decimals.

The old truism still holds good that however economically the engine may work, unless the greatest available heat of the fuel is utilised in generating the steam the result, as measured financially, will be disappointing.

I have no hesitation in saying that in stationary boilers it is more than doubtful whether the average amount of heat obtained from the fuel and converted into useful work in generating steam, exceeds 55 % of the calorific value of the fuel; or whether the average combined efficiency of the boilers and economisers employed in the industries of this country is more than 65 %. There is no valid reason why, in a properly designed plant, 80 % efficiency should not be obtained from the boilers and economisers combined, and yet this result is, to say the least, uncommon.

Sooner or later, when steam users take a more intelligent interest in the matter, we may look for the employment of designs of boilers suitable for the purpose in view; better draught, natural or artificial, as circumstances render it desirable; greater attention to the purification and heating of

feed water; firing by machinery where any advantage is to be gained thereby; regulation of the air supply to suit the fuel and style of firing; stoppage of air leaks, and the employment of firemen who have brains and are paid for using them in their work. Such conditions would result in an all round increase in efficiency of at least 10%.

Think of a saving of 10% of the many millions of tons of fuel which are annually consumed in the furnaces of steam boilers; converted into money it would liquidate the cost of the Boer war, and reduce the income tax to the vanishing point in a very few years.

The development of the gas engine is also a subject of very considerable moment to engineers. For very many years gas engines have been used with excellent results when the power required has been moderate, dispensing with the steam boiler and engine, and the ashes and dirt inseparable from the combustion of coal. The size of gas engines has gradually increased, until within the last year or two engines have been constructed to give off several thousand HP. The chief development in this direction has been on the Continent, where very large gas engines are in operation, and it is reported, working satisfactorily. The manufacture of Mond gas on a large scale will no doubt give a further impetus to the production of heavy gas engines.

Whether the gas engine will ever seriously compete with steam engines of large power, except possibly in certain special industries, is a point which the future can alone decide. It is quite conceivable that in cases where gases exist in the nature of a waste product (as in ironworks after the residuals have been extracted from the blast furnace gases), and can be used direct in engines for generating power instead of first transforming the available heat into steam, a saving would be effected both in the cost per unit of power generated, and also in capital cost of boilers, brickwork and chimneys, &c.

By using producer gas manufactured from low grade fuel gas engines of moderate powers have been made a commercial success, but very large gas engines are still somewhat of an experiment, and extended experience of them will be necessary before they can be recommended as entirely satisfactory motors. When power gas can be produced in central stations and distributed over large areas, at a cost to the consumer of between 1d. and 8d. per 1,000 feet, the use of gas engines is bound to increase rapidly.

The future methods of travelling are not without interest. That electricity will eventually become the motive power on our railways is highly probable, but whether the Mono-railway will take the place of the double railway for passenger traffic, and the latter be relegated to carrying merchandise in full trucks of large capacity, with corresponding reductions of railway rates and charges, is problematical. I incline to the belief that some of these conditions will be brought about before the flying machine becomes a successful and popular means of transit.

The rapidity with which motor-cars are coming into use is common knowledge, and this industry is likely to become a much larger one in the near future, when the cost is so reduced as to place the motor-car within the reach of persons of moderate means.

The motor-lurries using our streets and hauling loads which one feels thankful the horses are spared from, indicate that motor-power haulage on common roads is competing with animal power, and the probabilities are strongly in favour of this method of transporting goods being greatly extended.

It is a source of much satisfaction to me that a British Company are about to make a bid for the blue ribbon of the Atlantic, held for so many years by our enterprising rivals, the Germans. That we should have been outpaced in this manner has been anything but creditable to the nation who taught the

Germans how to build ships, and run them, and I rejoice that this state of things is to be altered, even although it may prove to be at some expense to the taxpayer. It is stated that the two new Cunarders will be 750ft. long × 76ft. beam, with a displacement of 80,000 tons and a horse-power of 50,000, to give an *average* speed of 25 knots.

It is a matter of the utmost importance to us that we should preserve our maritime supremacy, both naval and mercantile, and although the wisdom of granting subventions to merchant steamers, except for national services rendered, is questionable, if, as I doubt, it should be found in practice that such a course is necessary, we must adopt it.

This brings us to the consideration of the position we shall occupy among the nations in the time to come, as producers of engineering work. We are all too familiar with the erstwhile frequent newspaper statements that we were being ousted from foreign markets by American and German competitors. If the writers of many of these alarmist articles had taken the trouble to study the Board of Trade returns of our exports of steam engines and machinery, instead of being so ready to jump to conclusions on erroneous data, they would not have found any indications of our decadence, as the following extracts prove:—

EXPORTS IN 12 YEARS FROM 1890 TO 1901 INCLUSIVE.

	Locomotives and other Steam Engines.	Machinery and Millwork other than Steam Engines.	Total of Steam Engines, Machinery and Millwork.
1890	£4,442,858	£11,967,808	£16,410,661
1891	3,923,872	11,893,643	15,817,515
1892	3,225,816	11,572,900	14,798,716
1893	3,274,395	10,643,148	13,917,543
4 years Totals	£14,866,936	£46,077,499	£60,944,485
1894	3,065,103	11,140,112	14,205,215
1895	2,786,967	12,428,143	15,215,110
1896	3,286,353	13,727,897	17,014,250
1897	3,024,187	12,231,415	16,255,602
4 years Totals	£12,162,610	£50,527,567	£62,690,177

1898	3,631,488	14,748,588	18,380,076
1899	3,875,543	15,777,573	19,653,116
1900	4,095,341	15,524,443	19,619,784
1901	4,273,688	13,581,647	17,855,335
4 years Totals	£15,876,060	£59,632,251	£75,508,311
1902	£4,777,713	£13,974,099	£18,751,812

By dividing the twelve years under review into periods of four years we average, in some degree, the periodical cycles of good and bad trade.

For the four years ending with 1897, the value of our exports of steam engines and machinery was only 2·86 % more than in the preceding four years. A very different condition is, however, revealed by a comparison of the total for the next four years, ending with 1901, for during this period an increase of not less than 20·44 % was recorded over 1894—1897, or 23·89 % more than in 1890—1893.

The pessimist may argue that the time covered by the years 1898—1901, was one of exceptional prosperity and high prices, both of which premises are to some extent true, but against this has to be set the great engineering strike which interfered so seriously with production, and the decline in prices which began during 1900, and has since continued. Prices during 1902, although possibly not down to the level of 1897, for some classes of work, are certainly very considerably below those ruling in 1899—1900, and yet the value of mechanical engineering exports for last year (1902) is only ·66% less than the average of the previous four years, and 4.58 % lower than for the best year, 1899 ; but still an increase of 23 % over the average of the first four years under review, 1890—1893.

If these figures have any meaning at all it is that Britain has more than held her own in the world's markets for engineering work. This too is only part of the story, for in the last few

years very large sums have been spent on engineering work in industrial development at home.

To whatever causes it may be attributed, foreign competition, native enterprise, or otherwise, the fact remains that during the last four or five years there has been such a reorganisation, extension and installing of new engineering works as has never before been experienced in Great Britain. Many firms have been thoroughly awakened to the danger of becoming obsolete, realising that "sitting still" spells industrial extinction, with the result that some millions sterling have been expended in bricks, mortar, and improved machinery with a view to increased out-put at lower costs.

Among the progressive firms this district is exceedingly well represented, and I am probably well within the mark in estimating that not less than £700,000 to £800,000 have been invested in this manner within three or four years in the immediate neighbourhood of Manchester, without taking into account the reputed expenditure of £1,700,000 by the British Westinghouse Co. at Trafford Park.

This putting of our house in order has placed us in a much better position than we have ever previously occupied for meeting competition, but the changes have been so quietly and unostentatiously effected as to have attracted little more than local attention, although they have not escaped the notice of some of our friends, for Mr. James Boyle, the United States Consul at Liverpool states in his annual report that "England is more able now to meet competition in neutral markets than she has been in recent years." If any tangible evidence were needed of the happy effect this reorganisation has already had on our trade, it is furnished by a comparison of the value of mechanical work exported last year with that of 1901.

In spite of the lull in trade in almost every part of the world except America, and of the low prices ruling, the value of work

sent abroad during 1902 exceeded that of 1901 by a little over 5 %.

Fortunately for our future, Britishers are recognising in increasing numbers that if we are not to be left behind, the old apathy and indifference towards what is being done in other countries must be abandoned, and that we must assess at its true value the development in the science and practice of engineering amongst our competitors, adopting such improvements in the conduct of our businesses as are applicable to our conditions.

Just as every sensible man can and does learn something from contact with other common-sense men, so can every nation, not too hide-bound to learn, profit by intercourse with other manufacturing nations. By no means the least of the hopeful signs of the present is the greater frequency with which British engineers are visiting other countries and studying their industries, and the most progressive and prosperous concerns to-day, are those whose principals and members of staffs have made such pilgrimages. One of the best investments which employers could make would be in going themselves, and sending a certain number of their employés every year to the Continent and America to gather information and ideas of how to do, and how not to do things.

That the old order of conservatism is passing away is well exemplified by the innovations taking place in connection with the production of pig iron, and finished steel. Very heavy expenditure is being incurred in various parts of the kingdom in modernising blast furnaces and steel plants, in order to increase output at lower costs, to enable us to compete with other countries in this very important industry.

In this connection the recommendations of the Engineering Standards Committee for the reduction of sections of structural steel from sixty-three to twenty-three standard sections, are

very much to the point. It is estimated that by adopting the revised standards, a saving of not less than 5/- per ton of rolled sections will be effected.

Last year I spent a few weeks in the United States, and I am free to confess that I was very considerably impressed by some of the methods in vogue in that country. Any expectations of finding the men working excessively hard were not realised; in such works as I visited—and I spent a good deal of time in some of them—I failed to discover any evidences of exhausting labour, but on the other hand there was an absence of that happy-go-lucky, wandering-about-with-a-piece-of-wood fashion, which we are so painfully conscious exists in some of our works in Britain. Each man appeared to know his job, and to stick at it, and sullen faces were the exception. In the administrative and commercial departments the contrast between American and British practice was startling, and revealed the great factors tending to the success of American enterprises—enthusiasm and loyalty.

The extensively held opinion that the American fetish is dollars, is a mistake; the mainspring actuating them being, as far as I could judge, an intense desire and determination to bring to a successful issue whatever piece of work or business they are engaged on. The enthusiasm and belief in themselves, and the concerns with which they are connected, is superb; they seem to work because they like it, and as though the success of the firm was a matter personal to themselves. There is possibly an obverse side to this shield even in America, for enthusiasm and loyalty imply competent and hard working principals, and fair treatment and encouragement of employés, who must themselves be efficient; it is too much to believe that such conditions are universally existent in any country.

It is admitted on all hands that the British workman is unsurpassable, and in America he is highly appreciated on

account of getting more work through his fingers and of better quality than the natives, so that it is neither in the workman or in the quality of American work turned out—some of which is first-rate, and some is not first-rate—that any danger is to be apprehended. Where the Americans have the chief advantage over us is in the spirit and sentiment animating principals and officials alike, causing them to improve themselves and to put forth their very best efforts in the work they have to do. We want more of this spirit of enthusiasm in our engineering establishments, with its resultant effects, to place us in the best possible position to meet competition.

Who among this audience does not know of far too many young men—so-called engineers—who for any liking or qualification they possess for the profession, are in no way entitled to be described as such; men who think more of sport and athletics, than of God's blessing—work; and to some of whom perpetual holiday with sufficient income to maintain them in idleness would be no hardship, but satisfy all their ambitions. There is no room for such useless creatures in engineering.

Who is responsible for the importation of these drones into the engineering hive—not necessarily the youths themselves, but their parents, and more particularly employers. When employers make it conditional on entering their works that apprentices, improvers, or draughtsmen shall prove to their satisfaction that they have not only a rudimentary education, but that they also have a real liking for engineering, and mean to work, the present low mediocrity will be very quickly raised to the benefit of all concerned. The remedy lies with employers and heads of departments, who will find no lack of suitable material if they will but exercise discretion in selecting their employés, and in rejecting those who, after fair trial, fail to exhibit signs of capacity or enthusiasm for their work. It matters

little whether the enthusiasm bubbles out of a youth, or whether it be of the quiet dogged nature which stimulates him to tackle and overcome difficulties without fuss; so long as the real quality is there the rest will follow.

Much can be done to devolop this germ of enthusiasm by judicious encouragement; and it is the simple duty of every engineering employer to not only grant all possible opportunities to enable youths to improve themselves by attending technical classes, but to insist on such opportunities being used. This is a course which is being adopted by some large firms with excellent results, and it is to be earnestly hoped that eventually, the very great majority of lads who are taken into engineering works will be such as possess sufficient education and grit to become really useful men in whichever department their work may lie. There would then be no lack of well-grounded students able to take full advantage of the higher technical education offered by such institutions as our magnificently equipped Manchester School of Technology. It has been a reproach against this country that we have been far behind Germany and America in providing proper facilities for obtaining a sound scientific technical training; the ground for such reproach no longer exists in Manchester and other industrial centres, but where are the students to utilize the facilities provided? Intelligent students must be found, and in considerable numbers, if we are to continue to prosper.

A feature in the economic position, full of good omen, is the change—amounting to almost a revolution—in the attitude of the workmen towards progress. The introduction and acceptance of the "premium" system of payment; the encouragement and rewarding of workmen to make suggestions regarding improved methods of producing work; the visits of the men and representatives of trades unions to other countries to investigate the conditions of labour, are all steps tending to break down the

dead level of mediocrity so fatal to advancement, and to stimulate healthy emulation leading to greater efficiency, and to that community of interests which shall in the future prevent the resort to suicidal "strikes" as a means of settling disputes.

The manner in which the necessities of present day conditions are being realised and dealt with by an ever growing number of those engaged in the engineering industries; the greater attention which is being paid to technical and commercial education; the recent reform in the patent law, principally brought about by the agitation instituted by the Manchester Chamber of Commerce, and other signs of the times, justify me in the confident prediction that we shall be able to retain our engineering grip on neutral markets in spite of all comers, History has repeatedly proved that although somewhat slow to move, once his inertia *is* overcome the Britisher does full justice to the characteristics developed by the storm and stress of past centuries, and all he requires to ensure success in his undertakings is to be true to his best traditions, and to himself.

What part will this Association of Engineers fill in the future development of Engineering? Are we to sit down and rest content with the fact that our names are registered in the roll book of members, or are we to be real live component parts of an Association which shall prove to the world that Lancashire is the hub of the engineering industry, and that what Lancashire thinks in engineering to-day the engineering world will say to-morrow? The answer rests with ourselves.

Included in our ranks are many of the best brains and greatest workers of this country, and it is only necessary for each member to contribute his share to the general well of knowledge and usefulness, to make our Association first among all engineering societies in the quality and value of the information flowing from it, to the advantage

of not only its own particular members, but of the whole engineering world. It is only fitting that the district in which aboured such men as Joule, Nasmyth, Fairbairn, Roberts, Whitworth, and other Engineers whose names will never perish, should perpetuate their memory by disseminating reliable information, thus maintaining and increasing its reputation; by what means can this be so well done as through our Association. The day of jealously guarded engineering secrets is passed, and the best engineers of this country will be those who possess not only the faculty of assimilating knowledge, but who also are willing to draw on their stores of wisdom for the enlightenment of their compeers.

We have among our members a very large fund of special engineering knowledge and experience of the highest order, which it is their duty to place at the disposal of their fellows, remembering that the man who imparts most is he who learns most. The importance of the good work which this Association has done in the past cannot be estimated, and its usefulness is still increasing. Last year some good papers were read before the Association, and papers are to be read during the present Session on such interesting and instructive subjects as Steam Turbines, Recent developments in Gas Engines, Pneumatic Tools, The Premium System of Remuneration, and the Practical Training of Engineering Employers, all of which subjects are of the greatest concern to engineers.

The tests of tool steels which are being carried out by the Association at the School of Technology, with the cordial co-operation of the Municipal Technical Instruction Committee are progressing, and much useful information to engineers will accrue from them. Some members of your Council, and the members of the Technical Instruction Committee, as well as the Engineering Staff of the School of Technology, are devoting a very large amount of their valuable time to these tests, and the

Association, as a whole, is under deep obligations to them in the matter.

There are other fields of research work in which our Association might engage with beneficial results to the engineering profession, and any suggestions of members in this direction will be carefully considered.

It is within the power of our Association to give a great impetus to the better training of the youths who are adopting engineering as a profession, by evincing greater *practical* sympathy with the higher technical education imparted at the Manchester School of Technology. Some of the members are helping this good work forward by taking into their works youths who have completed a technical course, and I commend this example to your favourable consideration. Although the youths received from the technical institutions may not come up to expectations in all cases, a little patience with, and interest in them will secure good results. The closer our members come in touch with the Technical School authorities the greater will become its efficiency, for it is only by the union of practice with science that the most successful results are attainable.

The Gold Medal scheme which has been initiated will, I hope be the means of stimulating our younger members particularly, to offer papers to the Association on subjects with which they are specially concerned, and thereby prove of benefit to themselves and others. There is every reason to look forward with confidence to increased usefulness and efficiency of our Association, and to prophesy that in the not distant future it will occupy an even higher than its present position, as a fount of reliable data of the greatest service to the greatest number of engineers.

VOTE OF THANKS.

Mr. HENRY WEBB said that he esteemed it a very great pleasure to have the honour of proposing a hearty vote of thanks to the President (Mr. E. G. Constantine) for such an admirable and interesting Presidential Address. He thought that although they were not allowed to discuss or criticise the paper, yet, if they underlined the portions which chiefly applied to each of their own imaginations, he was certain they would find plenty of food for thought and reflection. He himself was particularly pleased with the common-sense running all through the address.

He then proposed a hearty vote of thanks to the Chairman for the Address.

Mr. M. INGRAM remarked that he also very much appreciated the presidential address which they had just heard. He knew that an address of this character was a labour of love, and that it was a very difficult matter to conceive it.

He had therefore the greatest possible pleasure in seconding the vote of thanks.

Mr. ALFRED SAXON observed that he was sure that all the members appreciated such a masterly address, and he had much pleasure in supporting the vote of thanks.

The PRESIDENT (Mr. E. G. Constantine) in responding, said that he was much obliged for kind remarks made by the previous speakers. He thought that at the present time, the engineering profession did not generally shine in imagination, was to be regretted.

In conclusion, he observed that particular attention should also be paid to scientific mechanical research work, and if any of the members could give some time to this subject, he was sure they would not be sorry for it.

He thanked them all sincerely for the manner in which they had received his address. The proceedings then terminated.

STEAM TURBINES FOR POWER STATIONS AND FACTORIES.

READ SATURDAY, 31ST JANUARY, 1903,

BY

Mr. R. M. NEILSON,

MANCHESTER.

The steam turbine as a scientific toy dates back to the second Century B.C.; but, as power stations were not then much in vogue and slave power for factories was comparatively cheap, it is not surprising that the industrial value of the steam turbine was not recognised till a much later date.

After being shown off for 1700 years as an interesting baby, the steam turbine was put to earn its living; but, like many of us, it had to start its engineering career by doing work of a very humble nature. It used to be the custom, I am told, to roast meat before a fire by sticking it on a spit or broach which was kept rotating in order to turn all sides of the meat towards the fire. Many devices were used for rotating the broach, and one was to employ a dog which, by means of simple mechanism kept the broach slowly and constantly rotating. This plan worked fairly well if a good dog was employed; but some animals had an unfortunate habit of clawing the meat, if not running away with it altogether.

It appears that in those days people had the same objection to losing their dinner that they have now, and in consequence a German mechanic in 1577 conceived the idea of employing a re-action steam wheel to turn the broach. I have not been able to get much information about this early steam turbine; but a little consideration will lead us to infer that it was not

an economical success. With steam jets situated 6in. from the axis of rotation, the wheel would require to rotate at over 10,000 revolutions per minute, to have fair economy; and a slight acquaintance with the laws of centrifugal force will show that after a few seconds rotation at this speed very little of the roast would be left.

After 1577 many attempts were made by experimenters in different countries to successfully employ the momentum of steam to drive a rotary engine, and many eminent men have expended time and thought with this object; but it was not until De Laval and Parsons, undaunted by centuries of failure, attacked the problem, that the difficulties were removed, the details of construction perfected, and the steam turbine transformed from a mere toy into one of the greatest prime movers of the present day.

Too much credit cannot be given to these two men for the work they have done. It was easy to conceive the idea of driving an engine by steam on the turbine principle, but to make such an engine workable and efficient was a very different matter, and required a combination of perseverance. mathematical and engineering ability such as very few possess.

The great difficulty in employing the momentum of steam was owing to its excessive lightness. When we remember that a cubic foot of dry saturated steam at atmospheric pressure is less than one sixteen-hundredth of the weight of a cubic foot of water, it will at once be evident to us that any machine which depends on the weight of a fluid will have to be very differently constructed when dealing with such steam than when dealing with water.

The heat that is given up by a pound of saturated steam at the comparatively low pressure of 50lbs. per square inch (gauge pressure) in being reduced to water at 85 degrees Fah. is 1,120 British thermal units. If all this heat were converted into

kinetic energy with which alone we can deal in a turbine, the steam, or rather the water condensed from it, would have to have a velocity of 7,470ft. per second.*

Or, to take a more natural supposition, suppose that the same steam were to expand adiabatically, employing its heat energy to give itself kinetic energy till its temperature fell to 85 degrees Fah.; then 21 per cent. of the steam would be condensed; the heat energy given up would be 287 B.T.U., and the velocity acquired would be 8,780ft. per second. The velocities derived from high pressure steam are of course greater than this.

It was this extreme lightness and excessive velocity which baffled most of the early experimenters on the steam turbine.

In the De Laval steam turbine the heat energy of the steam is converted into kinetic energy as it enters the turbine casing where a single turbine wheel specially and cleverly designed to deal with high fluid velocity absorbs as much of its energy as it can. This conversion of the heat energy of the steam into kinetic energy is accomplished by means of a diverging nozzle such as that shown in Fig. 1. The steam just before it

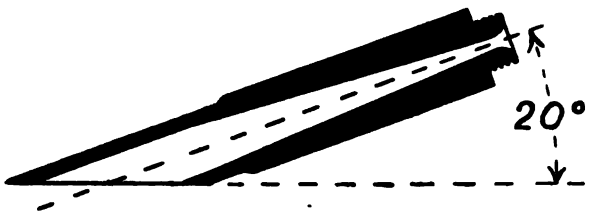

Fig. 1.—Nozzle of De Laval Turbine.

enters the small end of the nozzle has the initial pressure and the temperature corresponding to this (or above this if superheated steam is used) while the velocity is practically nil. By

* K.E. of steam $= \frac{WV^2}{2g} = 1{,}120 \times 775.$

Therefore $V^2 = 2 \times 32{\cdot}2 \times 1{,}120 \times 775$

$V = 7{,}470.$

the time the steam has reached the large end of the nozzle, it has acquired an enormous velocity while its pressure is very nearly that of the condenser. Its elastic properties are now of no further use and to all intents and purposes it is merely a mass of rapidly moving particles. These particles enter the turbine buckets and give up their kinetic energy to rotate the wheel. Thus in a thousandth part of a second the steam gains a tremendous velocity and loses it again.

In order to make the best use of the excessive velocity of the steam, the vane or bucket speed in a De Laval turbine has to be very high. The want of a sufficiently strong and light material prevents the vane speed being as great as is desirable. It is well-known to engineers that the centrifugal force on rotating bodies is very great at high velocities; but the enormous values sometimes reached are appreciated only by a few. A quarter of a pound of iron occupies a volume of less than one cubic inch; and yet this small piece of metal if placed on the periphery of certain De Laval turbine wheels running at their normal speed would require the pull of a strong locomotive to hold it in. In some recently built large De Laval turbines however a careful design and the use of the best material has allowed of a vane speed which does not fall far short of the best possible. As the turbine wheel is necessarily of very moderate dimensions even for large powers, the number of revolutions per minute is very great.

The relatively greater diameter of wheel employed in a large power turbine than in a small power one allows of the same vane speed with a reduced speed of rotation; and hence a 300 B.H.P. De Laval turbine wheel runs at about 7,000 to 11,000 revolutions per minute, while a 5 B.H.P. turbine makes about 30,000 revolutions per minute. Greater vane speeds are however employed in the larger sized De Laval turbines than in the smaller sizes. In the former the velocity of the

periphery of the wheel is sometimes more than a quarter of a mile per second, a speed at which the wheel would roll to Liverpool in two minutes and would roll round the world in 28 hours.*

To withstand the great centrifugal force the turbine wheel is peculiarly constructed. Fig. 2 shows the nature of the section employed. It will be seen that the most material is placed near the centre where the velocity is least. The wheel is to a

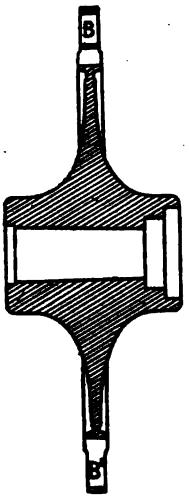

Fig. 2.—De Laval Turbine Wheel.

certain extent hung from the centre, that is to say, the inside layers of metal help to support those beyond them. The weak point of the wheel is at the periphery and purposely so. Should the wheel fracture here, the parts detached would be comparatively light and consequently the damage reduced to a minimum; while the absence of the blades would at once prevent any increase in the speed of the wheel. The larger wheels where extreme velocities are used are made with a solid

* Since writing this, I find that Mr. Konrad Anderson has used a similar illustration.—R.M.N.

boss, the shaft being made in two parts each of which is attached by a flange to an end of the boss, as shown in Fig. 8.

The diameter of the wheel of a 10 B.H.P. De Laval turbine is usually about 4½ to 5in., that of a 50 B.H.P. turbine about a foot, and the wheel of a 300 B.H.P. motor has been made 30in. in diameter.

The spindle which carries the wheel, owing to its great speed, does not require to be of large diameter to transmit the power, and the employment of a light and flexible shaft forms a convenient means of obtaining smooth running, to secure which the wheel must of course be allowed to choose its own axis of rotation. To one inexperienced with very high speeds of rotation it seems odd to see 100HP transmitted by a shaft only about ⅛ of an inch in diameter.

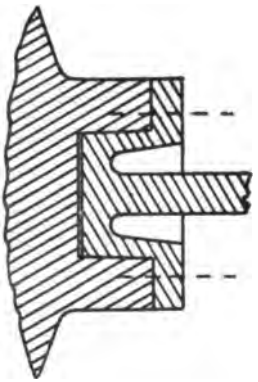

Fig. 8.—Connection of Shaft to Wheel of large De Laval Turbine.

To reduce the high rotary speed to a more manageable quantity toothed gearing is employed and this is of the helicoidal type. A pinion on the turbine shaft drives a wheel on the power shaft or, as is usually the case with large power machines, the pinion drives two spur wheels each on a power shaft, the power shafts being situated one on each side of the turbine shaft as shown diagrammatically in Fig. 4 where T is

the turbine wheel, D the turbine nozzle, H the turbine spindle, N the pinion and W W the gear wheels. E E are the power shafts and P P are pulleys or dynamo armatures.

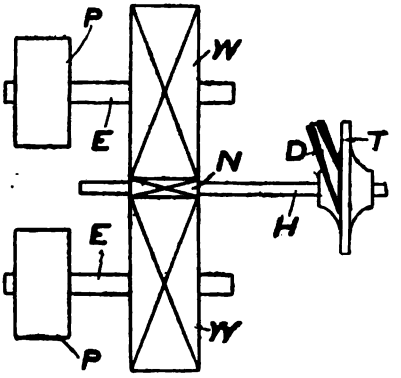

Fig. 4.—Arrangement of Gear Wheels in De Laval Turbine.

The gearing is an essential part of the machine and when brake horse power is mentioned it is always that of the power shaft or power shafts that is meant. The speed of rotation given is also to be taken as that of the power shaft or shafts unless particularly stated to be otherwise. The gearing ratio is commonly 10 to 1.

A 225 B.H.P. De Laval turbine and dynamo is shown in Fig. 5, Plate I. This was constructed by Messrs. Greenwood and Batley Limited, of Leeds. The casing on the right with the small hand wheels contains the turbine wheel. The small wheels control the nozzles, one or more of which can be shut to reduce the power of the machine. The steam pipe connection is seen at the top of the casing. The next casing contains the gear wheels. The turbine spindle extends no further than this casing, but gives up its power therein to the two power shafts which pass out of the casing at the left and are connected by means of flanges (which can be seen) to the armature spindles. The field magnets and armatures can be seen towards the left

of the figure, and the commutators are just beyond and just inside the last bearings. The governor mechanism can be seen between the turbine casing and the gear case.

In a machine of this size, room is provided for 9 nozzles, and all of these are employed at full load when the steam pressure is 50lbs. When a higher pressure of steam is used, a less number of nozzles is employed, and the surplus holes for nozzles are plugged up or blind flanges put on.

Fig. 6, Plate I, shows a 225 B.H.P. De Laval turbine-motor constructed by Messrs. Greenwood and Batley Limited. Each power shaft makes 1,000 revolutions per minute and carries a driving pulley which on account of the high speed of rotation is made only $19\frac{5}{16}$in. in diameter, while it is $17\frac{1}{8}$in. wide. The pulleys are arranged for driving in the same direction.

The blade of a De Laval turbine is shown in longitudinal section in Fig. 7 which also shows how the blade is attached to the rim of the wheel. The attachment is very important on

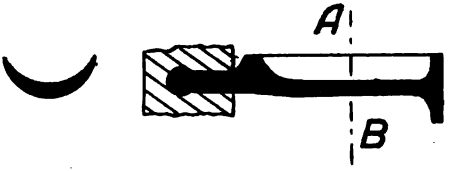

Fig. 8. Fig. 7.

Blade of De Laval Turbine showing method of attachment to Turbine Wheel.

account of the magnitude of the centrifugal force. Fig. 8 shows a cross section of the blade on the line A B of Fig. 7. The angles at inlet and outlet are the same. A front and a back view of a blade are shown at B and B^1 respectively in Fig. 2.

The friction between the steam (and suspended water) inside the turbine casing and the turbine wheel is a very important consideration. This friction is independent of the load on the turbine but depends on the pressure inside the turbine casing

and on the speed of rotation. It is important therefore in condensing turbines to have the vacuum as low as possible, not only on account of thermo-dynamic reasons but in order to reduce friction. The friction is found to be almost exactly proportional to the pressure inside the turbine casing, other conditions being the same. Thus, if a De Laval turbine wheel takes 10HP to drive it idle with a condenser pressure of 1lb. abs., it will require 150HP to drive it idle at the same speed when exhausting into the atmosphere.

The friction also depends on the nature of the fluid inside the casing. Dry steam causes less friction than wet steam and superheated steam less friction than saturated steam.

In May and June of last year tests were made of a 800 B.H.P. De Laval turbine by Messrs. Dean and Main, of Boston, U.S.A. The turbine in question is installed at the works of the American De Laval Steam Turbine Company, at Trenton, N.J., and is employed to drive two dynamos which supply direct current for actuating the tools in the machine shop. During some of the tests a water rheostat was used to absorb some of the energy as the tools did not require all the current generated.

The steam consumption was obtained by measuring the feed-water supplied to the boiler. In the tests with saturated steam the moisture in the steam was deducted; but the condensation that occurred after the steam had entered the chamber supplying the turbine nozzles was not deducted. When superheated steam was used, the amount of superheat was determined by a bare-stem Green thermometer inserted in a well of cylinder oil in the steam pipe between the throttle and the governor valves.

The efficiencies of the generator at different loads were ascertained. The electrical instruments were checked at the works of the Weston Electrical Instrument Company, Waverly Park, N.J., and the brake horse-power computations were made

by Messrs. Stone and Webster, of Boston, and by the De Laval Electrical Engineer.

TABLE I.

Summary of Tests of 300 B.H.P. De Laval Steam Turbine at Trenton, N.J., U.S.A.

Duration of Test in Hours.	Average Steam Pressure before Governor Valve in lbs. per sq. in.	Average Steam Pressure after Governor Valve in lbs. per sq. in.	Average Vacuum in inches of Mercury.	Barometer in inches of Mercury.	Average Temperature of Room in degrees Fahr.	Averg. Superheat before Governor Valve in deg. Fahr	Number of Nozzles open.	Revolutions per minute of Generator.	Average Brake Horse-Power.	Lbs. of Steam per Hour.	Lbs. of Steam per B.H.P. Hour.
6	207·0	198·5	27·2	30·18	83	84	8	750	352	4906	13·94
2	207·4	197·0	27·4	30·07	90	64	7	756	298·4	4282	14·35
6	201·5	197·2	27·4	29·79	89	13	5	745	196·2	3047	15·53
4	206·4	196·9	26·6	29·92	90	0	8	747	333·0	5052	15·17
2	207·3	196·5	26·8	29·90	97	0	7	746	284·8	4430	15·56
2	207·6	195·8	27·3	29·83	97	0	5	751	195·2	3229	16·54
3	201·5	197·9	28·1	29·81	80	0	3	751	118·9	1950	16·40

The result of the last test namely 16·40lbs. of dry saturated steam per B.H.P. hour at about one-third load should be particularly noted.

Several attempts have been made to produce a turbine which, while retaining most of the simplicity of the De Laval type, will allow of more of the energy of the steam being utilized and also allow of a reduced vane speed.

The Seger steam turbine is an example of one such attempt. It seems to have several good points and has given some fairly good results as regards steam consumption.

Fig. 9 shows a Seger steam turbine in front elevation partly in section. Fig. 10 is a side elevation partly in section of the same machine. The turbine discs *a* and *b* are mounted respectively on shafts *c* and *d* which are in line but are not directly connected to each other. The discs are enclosed in a box; and steam is projected from nozzles against the blades of the first disc from which it passes through holes in a diaphragm

and acts on the blades in the second disc. Fig. 11 shows a nozzle and parts of the two discs, the arrows indicating the direction of flow of the steam and direction of rotation of the discs. The one disc rotates in a reverse direction to the other and therefore the direction of flow of the steam on leaving the first wheel is suitable for acting on the second wheel. In a 60 B.H.P. motor tested in Sweden, the first wheel *b* made 8,400 revolutions per minute, and the second wheel *a* 4,200 revolutions per minute. The shafts *c* and *d* carry small pulleys *e* and *f* which are inversely proportional in diameter to the speeds of rotation of their respective discs *a* and *b*, so that the

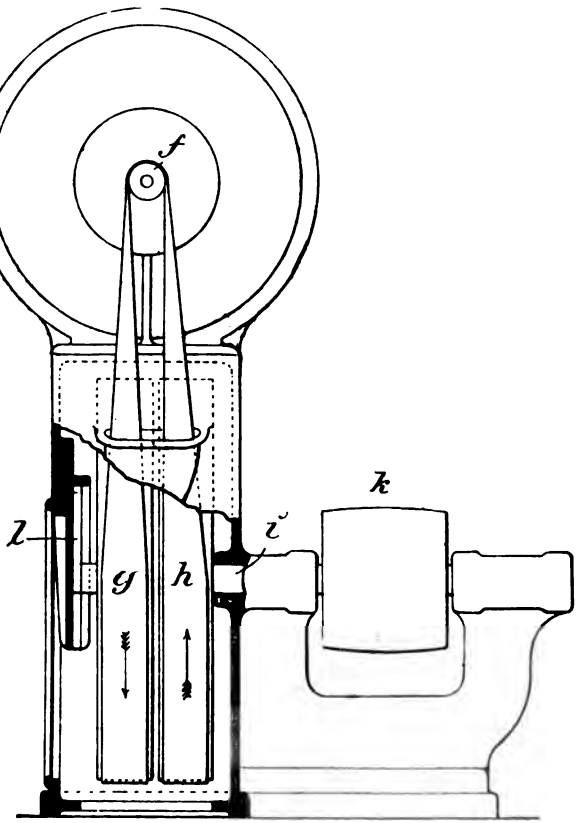

Fig. 9.—Seger Turbine: Front Elevation.

peripheral speeds of the two pulleys will be the same. An endless belt passes round the pulleys *e* and *f* and round two large pulleys *g* and *h* arranged below the turbine wheels. The pulley *h* is keyed on the shaft *i* which carries the driving pulley *k* from which power can be taken. When the machine is employed for

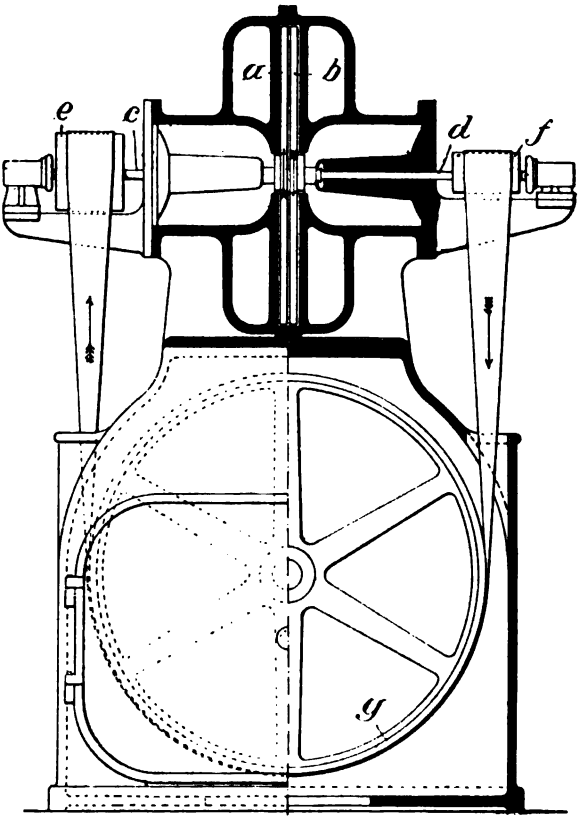

Fig. 10.—Seger Turbine.

Fig. 11.—Nozzles of Seger Turbine.

driving a dynamo, the armature spindle is coupled direct to the shaft *i*. The pulley *g* is only a guide and tension pulley; its vertical position can be adjusted by means of the piece *l* so as to adjust the tension of the belt.

Fig. 12, Plate II, shows how the machine can be opened up for inspection.

Steam is admitted to the turbine casing through a regulating valve which may be controlled by a governor situated on the shaft *d*. The passage of steam through the separate nozzles can be controlled by means of spindles and hand wheels as in the De Laval turbine. Some of these wheels can be seen clearly in Fig. 13, Plate II, which shows a Seger steam turbine provided with a driving pulley. Fig. 14, Plate II, shows a Seger steam turbine coupled direct to a dynamo. These illustrations of the Seger steam turbine have been re-produced by kind permission from *Le Génie Civil*.

Fig. 15.—Nozzles and Buckets of Stumpf Steam Turbine.

Prof. Stumpf, of Berlin, has devoted considerable time to experiments on a steam turbine, something like the De Laval turbine. Instead however of dovetailing the blades into the rim of the turbine wheel, Prof. Stumpf cuts buckets out of the solid metal. Moreover, in the Stumpf turbine the nozzles are in the plane of the wheel instead of making an angle with the plane of the wheel as in the De Laval turbine. Fig. 15 shows part of the rim of a Stumpf turbine wheel and a couple of nozzles. Nozzles are arranged all round the wheel. A section of a bucket on the line *a b* of Fig. 15, may be either as shown in Fig. 16, or as shown in Fig. 17. The latter arrangement is of the same nature as the bucket of a Pelton water-wheel.

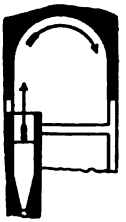

Fig. 16.—Single Bucket of Stumpf Steam Turbine.

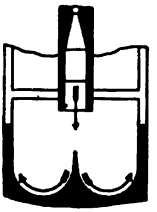

Fig. 17.—Double Bucket of Stumpf Steam Turbine

The section of the interior of each nozzle changes from a circle to a rectangle, the latter being the section at the outlet end of the nozzle. This construction allows the outlets of the nozzles to fit together and permits of a practically continuous stream of fluid entering the whole circle of turbine buckets.

Prof. Stumpf informs me that he has run an 1,800HP turbine on 6½ kilogrammes (14⅓lbs.) of steam per electrical horse-power hour.

The Allgemeine Elektricitäts-Gesellschaft, of Berlin, have undertaken the manufacture of the Stumpf steam turbine.

The type of turbine which is most extensively used for power stations is the Parsons. The nature of this turbine is now

fairly well-known to engineers. The steam is expanded gradually in passing alternately through fixed and moving vanes and in consequence the velocities are kept much lower than in the De Laval type and gearing is dispensed with. Parsons turbines are now usually constructed of the parallel flow type, that is the fixed and moving blades are arranged in parallel rings which are at right angles to the turbine spindle, the blades being radial to the turbine spindle. The steam is expanded down to the pressure in the exhaust pipe. The speed of rotation depends on the initial and terminal pressures, on the diameter of the rings of blades and on the number of these. Table II. made up from turbines now running gives an idea of the usual speeds of rotation; but the revolutions per minute can be reduced when necessary by increasing the number of rings of blades. The drop of pressure for each ring is thus reduced and the vane speed can therefore be lowered. The steam pressure also can be lowered by increasing the length of the blades, and thus giving more area for the steam to pass; or the pressure can be raised by shortening the blades, and thus reducing the area.

TABLE II.

Speeds of Rotation of Parsons Turbines (condensing).

Power of Turbine in Kilowatts.	Steam Pressure in lbs. per sq. inch.	Revolutions per Minute.
32	125	5,000
75	125	4,000
150	150	3,500
250	150	3,000
500	180	2,500
1,000	200	1,800
1,500	200	1,500
2,000	200	1,200

The power of the turbine is regulated by a valve (usually an equilibrium valve) which is actuated by a piston controlled by

a small relay valve. This relay valve is controlled by an electrical or centrifugal governor so as to allow steam to pass intermittently or in puffs through the main equilibrium valve. At full power the puffs merge into a continuous stream.

Fig. 18 shows diagrammatically a common form of governor

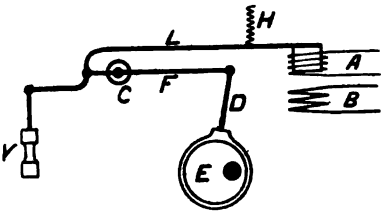

Fig. 18.—Diagrammatic Illustration of Governor Gear of Parsons Turbine.

mechanism. E is an eccentric driven by worm gearing from the turbine or dynamo spindle (or connecting sleeve). The eccentric rod D oscillates the lever F pivoted about the fixed centre C. This causes the lever L to pivot about its right hand end while its other end reciprocates the relay valve V. A is a shunt solenoid which according to the terminal pressure of the dynamo exerts a greater or less pull on the lever L against the action of the spring H so as to lengthen or shorten the duration of the steam puffs. With alternators a series coil B may also be used in order to compound for constant voltage. When a centrifugal governor is employed, it takes the place of the solenoid or solenoids and acts in a similar way to reduce or increase the duration of the puffs of steam.

Fig. 19, Plate III., shows a 3,000 HP steam turbine constructed by Messrs. C. A. Parsons & Co. for Milan. The overall length is 29ft. 6in. and the breadth is 8ft. 9in. The greatest height of the machine is 9ft. and its weight is about 35 tons. As can be seen in the drawing there are two cylinders, a high pressure and a low pressure, with an intermediate bearing. The exhaust outlet can be seen at the bottom and right hand end of the low

pressure cylinder. The large size of this opening should be noted; it will be afterwards referred to. The turbine makes about 1,260 revolutions per minute.

The exciters for turbine-driven alternators may be either driven direct from the turbine or may be driven by separate engines. The air-pump and circulating-pump are commonly driven by electric motors but may if desired be actuated by gearing from the turbine spindle. This latter arrangement is shown in Fig. 20, Plate II, which illustrates a 82 K.W. turbo-dynamo built by Messrs. C. A. Parsons & Co. The turbine makes 8,000 revolutions per minute, and the pump-rods make 100 up and down movements in the same time. The turbine, dynamo, condenser and pumps together weigh less than 6 tons and occupy a floor space of 14ft. 9in. × 4ft.

For the loan of blocks to illustrate Figs. 19 and 20, I am indebted to Messrs. C. A. Parsons & Co.

Figs. 21, 22 and 23, Plate IV., show in front elevation, end elevation and plan respectively a 1,000 K.W. continuous current turbo-generator supplied by Messrs. C. A. Parsons & Co. to the Newcastle and District Electric Lighting Company for use at their Close Works, Newcastle-on-Tyne. There are two similar dynamos either of which may be run independently of the other and the two armatures are interchangeable. The voltage is 500 and the revolutions 1,800 per minute. An automatic brush rocking gear is provided which is actuated from the turbine so that at any load the brushes are at the best positions on the commutators. The armature shaft is coupled to the turbine shaft by means of a claw coupling. Provision is made for expansion of the turbine cylinder by allowing the foot at the high pressure end to slide on the pedestal. Two valves are provided (as is usual) in the valve chest through which the steam enters the turbine cylinder. The first is an emergency valve while the second is operated by a relay device controlled

by the governor after the manner of that described with reference to Fig. 18.

Messrs. C. A. Parsons & Co. have recently constructed large power turbo-generators having an extremely low steam consumption at full power. For example the 1,500 K.W. turbo-alternator supplied by them to Neptune Bank Power Station near Newcastle-on-Tyne can be run on less than 18lbs. of steam per K.W. hour not counting the power required to drive the air-pump and circulating-pump which power however I believe is only about 34 kilowatts.

A Westinghouse-Parsons steam turbo-alternator is shown in Figs. 24, 25 and 26 in plan, front elevation and end elevation respectively. The writer is indebted for these views to an article by Mr. Burcham Harding, in the *Engineering Record*, New York.

The alternator which was constructed by the Westinghouse Electric and Manufacturing Company of America, has a capacity of 300 kilowatts. It is bi-polar and two-phase, the voltage being 440 and the alternations per second 120.

The turbine which is rated at 500HP was constructed by the Westinghouse Machine Co., Pittsburg, who in 1896 acquired the patent rights for constructing steam turbines of the Parsons type in the United States. The steam inlet is clearly seen in the Figs. and the governor valve not far from it at the high pressure end of the turbine. The turbine is of the parallel flow type and the steam in its passage from the high pressure end of the gradually widening cylinder to the low pressure end of the same, acts in succession on 58 rings of blades and is expanded about 96 fold, that is from 120 to 125lbs. gauge pressure down to from 1 to 1½lbs. absolute. The blades are about 8in. in length and at full load each contributes to the extent of about 1oz. to the force required to turn the shaft. Two exhaust outlets are provided, one on each side of the machine so that the

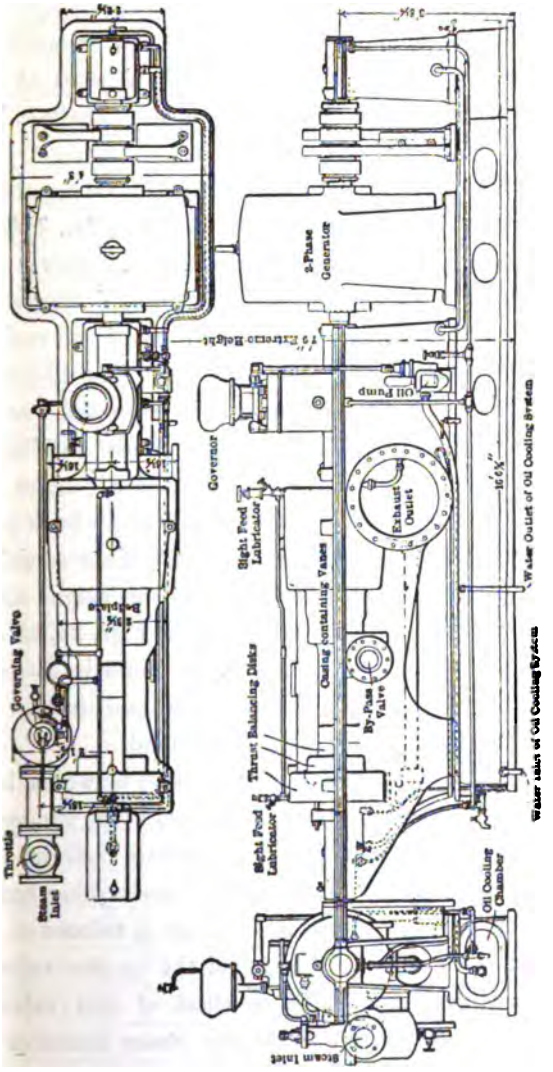

Fig. 24.

Fig. 25.

Fig. 26. Plan and Elevation of a 500 Horse-power Steam Turbine.—Westinghouse-Parsons.

exhaust pipe may be placed at whichever side is most convenient. (It is advisable to have the connection between a steam turbine and its condenser as short and direct as possible).

Forced lubrication is employed, the oil being cooled and used over again. The oil pump can be seen at the low pressure end of the turbine; it is driven from a worm situated at the coupling between the turbine and alternator shafts. The turbine runs at 8,600 revolutions per minute.

Three of these turbo-alternators are installed in the works of the Westinghouse Air-Brake Co., at Wilmerding, Pa., U.S.A., and employed for generating electric energy for power and lighting purposes in the works. Fig. 27, Plate V, shows the engine room. The machine in the front is one of two exciters and behind it can be seen the turbo-alternators. The oil-pumps and tubes of two of the machines can be seen and also the exhaust ports covered by blind flanges. Each turbine is carried on the same bed-plate as the alternator it drives and the bed-plates rest without holding down bolts on brick piers which are merely sufficient to carry the weight of the machines each of which (turbine, alternator and bed-plate) weighs about 25,000lbs. The principal sizes are given in Figs. 24, 25 and 26, but a better idea of the small bulk of the units is obtained by comparing the three 300 K.W. turbo-alternators in Fig. 27, Plate V, with the 10HP exciter in the foreground.

Each turbine is provided with a by-pass valve by which high pressure steam can, when desired, be admitted to the turbine at a point intermediate between its high pressure and its low pressure ends. Steam is so admitted when the turbine has to work at overload, or when the boiler pressure is reduced or the condenser vacuum impaired. The use of the by-pass valve of course reduces the efficiency. The effect of this valve is well seen in Fig. 28, which shows the steam consumption of one of the turbines, the lower curve being when run condensing, and the upper curve when run non-condensing. The by-pass valve has been opened in the latter case at a little over 200 E.H.P.

A large Westinghouse-Parsons steam turbine was lately tested in America by Prof. Robb, of the Electrical Engineering Rensselaer Polytechnic Institute. This turbine was built by the Westinghouse Machine Co., and is installed in the Pearl Street station of the Hartford Electric Light Company at Hartford, Conn., U.S.A. It is shown in Fig. 29, Plate V. The turbine directly drives a two-phase alternator, and the turbo-alternator was rated at 1,500 K.W. As however in one of the tests the output was an average of 2,000 K.W. for four hours,

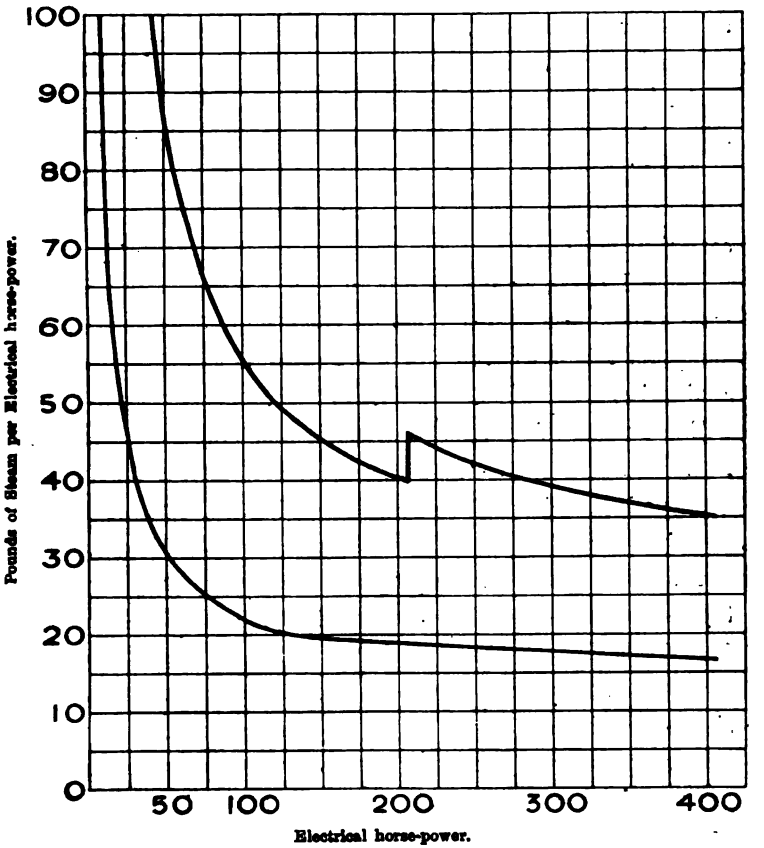

Fig. 28.

it would seem more proper to rate the capacity at a higher figure.

The total weight of turbine and generator in running order is about 175,000lbs., which at 2,000 K.W. works out at 87½lbs. per kilowatt. The length of the turbine and generator complete is 33ft. 3in., and its breadth 8ft. 9in. The weight of the rotating part of the turbine only is 28,000lbs.; its length over all is 19ft. 8in., and its greatest diameter 6ft.

There are in all about 30,000 fixed and moving blades, varying in length from 1¼in. at the high pressure end, to 8in. at the low pressure end. The exhaust outlet has an area of 10 square feet. Like the machines at Wilmerding, this turbine has a by-pass valve for use at high loads. The governor is actuated from a worm on the extreme end of the turbine shaft at the high pressure end of the turbine. This worm is also used to furnish power for operating the pump for the lubricating oil.

Table III. shows the results of tests by Prof. Robb, which were made under ordinary station conditions. The steam consumption tabulated is that of the turbine only, and not of the auxiliaries.

The British Westinghouse Electric and Manufacturing Co. Ltd,, are at present constructing four turbo-alternators for the Metropolitan District Railway Company. Each of these machines is designed for a normal capacity of 5,500 kilowatts, but to be capable of carrying an overload of 50%, making the maximum output of each unit 8,250 K.W. or about 11,000 E.H.P. These turbines will not only be the largest steam turbines ever built, but will be the most powerful single cylinder engines of any type whatsoever that the world has ever possessed. In fact there are very few multiple cylinder engines which exceed them in power. In spite of the enormous power of these engines, the extreme length, breadth and height

TABLE III.

Tests of Turbo-Generator at Hartford, Conn., U.S.A.

Test.		Load.			Length of test.	Steam, Mean Gauge pressure.	Barometer.	Vacuum at Turbine.	Superheat. Degrees Fah,			Steam Consumption.	
No.	Date. 1902.	Aver. K.W.	Max. K.W.	Min. K W.	Hours.	Lbs. per square inch.	Inches.	Inches.	Mean.	Max.	Min.	Lbs. per E.H.P. hour.	Lbs. per K.W. hour
1	Jan. 27	748	885	580	6	155·5	30·70	26·22	0	0	0	24·13	32·17
2	Jan. 28	1657	1820	1480	6	151·3	30·73	28·00	40·08	61·34	19·85	15·15	20·2
3	Feb. 1	1998	2185	1900	4	155·4	30·27	26·91	41·56	55·05	32·45	14·43	19·10
4	May 7	471	730	310	6	151·8	29·86	26·62	19·10	29·00	3·50	23·97	31·96
5	May 8	888	980	750	6	152·6	30·04	25·83	32·90	47·50	12·00	19·90	26·53
6	May 9	1371	1570	1110	6	151·9	29·81	26·26	32·10	38·60	12·50	16·46	21·94
7	May 12	834	940	660	6	153·2	30·26	27·26	35·40	45·10	20·10	18·50	24·60
8	May 13	364	520	150	6	153·1	30·06	27·40	29·0	41·00	2·50	25·10	33·47

of each are only about 29ft., 14ft. and 12ft. respectively. The overall length of turbine and alternator is 51ft. 9in. A by-pass valve is provided for use at high overloads. The alternators have stationary armatures and rotating fields. The steam pressure will be 165lbs. per square inch, and the speed will be 1,000 revolutions per minute.

There is still an opinion among some engineers that the steam turbine, although possessing many good points is a heavy consumer of steam. This is not surprising, because rotary engines as a rule are very extravagant and the steam turbine until a few years ago was undoubtedly behind a good reciprocating engine in point of economy.

The Hon. C. A. Parsons in a paper read before the North-East Coast Institution of Engineers and Shipbuilders on Dec. 19, 1887, said "The results we have so far actually obtained are a consumption of 52lbs. per hour of steam for each electrical horse-power with a steam pressure at 90lbs. above the atmosphere." This was an extremely good result for a species of engine only 8½ years old, but I should not think that Messrs. C. A. Parsons & Co. would like now to turn out any turbine except extremely small ones which could not run at half that rate of consumption.

Large steam turbines are more economical than smaller ones but there are I believe only a few reciprocating engines of any size which can rival in efficiency a modern Parsons turbine of the same power when run at full power. When run at half load however a reciprocating engine often has the advantage. In a paper read before the British Association at Belfast in September, 1902, Mr. Parsons stated that in a trial between a steam turbine and a Sulzer engine of the same power, the two were equal in efficiency when running at three-quarters load. The turbine was the better above that load; but below that load the Sulzer engine had the advantage.

This statement, although referring to one particular case, expresses very well, in my opinion, the present relation between Parsons steam turbines and good reciprocating engines; of course there are exceptions to every rule. I would like to emphasize however that the rule only applies to *good* reciprocating engines. The *average* reciprocating engine is now out of the running altogether as compared with a Parsons steam turbine in point of efficiency.

It is important to note (and is of course an obvious fact) that a saving of 5 per cent. of coal for an hour's running at half load will not compensate for a 5 per cent. excess for an hour's running at full load.

If it is desired in a steam turbine that the greatest efficiency shall be below full load then for all powers above the most efficient load a by-pass valve can be used as described with reference to the Westinghouse-Parsons turbines.

The total aggregate power of steam turbines at present in use or under construction or on order, in different parts of the world must be over 500,000HP. The greater portion of this total power is used or is intended to be used for driving dynamos and alternators, while the next largest portion has been designed for marine propulsion,

The application of the Parsons turbine to the propulsion of ships has shown it to be a formidable rival to the reciprocating engine for this purpose, and before many years are passed it will probably be competing with the reciprocating engine for many other purposes for which it is not now used. I might here mention in parenthesis (this not being a paper on marine propulsion) that in this country (besides ships built abroad) there have been built or are now building or on order 18 vessels fitted with steam turbine propelling machinery.

In the driving of factories slow speed reciprocating engines are very commonly employed which are geared up to drive the

line shafting. These slow speed engines are chosen for their economy and reliability and their calling for small attention; but, if an equally economical and reliable high-speed engine which calls for no more attention can be obtained, it will have many advantages over its slow speed rival. If the speed of the line shafting is fixed, then it is cheaper (excluding extreme cases) to gear down to this speed than to gear up to it. If the diameter of the driving pulley be kept constant, the belt or rope speed will also be constant; but the diameter of the driving pulley will be less in the case of gearing down than in the case of gearing up, and a consequent saving in cost will be effected. It is true that a large driving pulley reduces the weight of fly-wheel required by a reciprocating engine and can sometimes take the place of a fly-wheel. In the case of a steam turbine however which requires no fly-wheel, any saving in weight of the driving pulley is clear gain.

Now for example suppose that we have a 600 B.H.P. gearless steam turbine running at 2,000 revolutions per minute, and we wish it to drive several lines of shafting by means of ropes. If we place 8in. pulleys on the turbine shaft and 64in. pulleys on the driven shafts, then the driven shafts will rotate at from 220 to 240 revolutions per minute (the exact amount depending on the slip) while the rope speed will be about 4,000ft. per minute. 42 one-inch ropes or 75 three-quarter-inch ropes would transmit the power.

I hope this question will be dealt with in the discussion as there are many members better qualified than myself to speak on the subject of rope speeds and speed of rotation of shafting. The driving pulleys on the power shafts of a 100 B.H.P. De Laval turbine running at 1,050 revolutions per minute are commonly I believe 18in. in diameter which gives a rope speed of about 5,000ft. per minute. The belt speed from the machine shown in Fig. 6, Plate I., is also about 5,000ft. per minute.

I have dealt with the question of steam consumption and I have referred briefly to the question of the driving of line shafting. Let us now consider the other points of advantage and disadvantage of the steam turbine compared with the reciprocating engine.

In driving dynamos, the high rotary speed of the steam turbine allows a much smaller dynamo to be used than can be employed when coupled direct to a reciprocating engine. In comparing the cost of a steam turbine with that of a reciprocating engine for dynamo driving, the cost of engine and dynamo should be considered together.

The same remarks apply to the driving of alternators by steam turbines; but the saving is still greater in this case.

It has already been mentioned that for all except small powers De Laval turbines are provided with two power shafts, so that in dynamo driving two dynamos are used. This plan is adopted to obtain a better balanced construction. With very large power Parsons' turbines driving direct current generators, the latter are also made in duplicate, but for a different reason, namely to avoid commutator difficulties. The dynamos are of course arranged tandem in this case. For electric lighting on the three-wire system the double dynamo arrangement may be very convenient.

The turbine is at a disadvantage when a slow speed of rotation is required. When it was first tried for marine propulsion great difficulty was experienced in getting satisfactory results, as screw propellors, when rotated above a certain speed depending on their size, are very inefficient. However, the fact that the steam turbine has been got to work, and to work very satisfactorily for propelling vessels, shows us that it can probably be applied to a great number of purposes where a moderate speed of rotation is required. By splitting up a multiple expansion turbine, such as a Parsons, into two or

more cylinders, a moderate speed of rotation can be obtained without much loss of efficiency. This will allow a turbine to be used in cases where the speed of rotation of a single cylinder turbine of the requisite power would be too great. The several cylinders of the turbine can drive the same shaft or different shafts as may be desired.

A reciprocating engine, however well arranged and designed, usually causes much more vibration than a steam turbine. Now vibration is not only unpleasant but is decidedly harmful in many cases, and it is this smooth running property of the steam turbine which has been the chief reason for its adoption in several instances. The same characteristic of the steam turbine which allows it to run without vibration, namely the constant nature of the forces in its several parts, also enables it to run when simply resting on a support capable of carrying its dead weight. It is like an electric motor in this respect, except that the latter usually gives off its power by means of a belt, and provision has to be made to withstand the pull of the belt. A rotary converter or motor generator probably forms the best parallel to a steam turbine.

As regards floor space occupied there is not a great difference between that required by steam turbines and that required by some high speed vertical reciprocating engines. A slow speed horizontal engine of course occupies a very much larger floor space; and, if it is employed to drive a dynamo by means of a belt or ropes, the requisite floor space is enormously increased.

Table IV. compares the floor space occupied by several steam turbines and vertical reciprocating steam engines of different powers.

As a supplement to Table IV. I might mention that at the Temple Back Electric Lighting Station at Bristol, the space vacated by three Willans-Siemens steam alternators of a total capacity of 886 K.W. has been utilised for placing one 500 K.W.

TABLE IV.

Floor space occupied by Steam Turbines with Electric Generators, and Vertical Reciprocating Engines with Electric Genertors.

Description of Engine and Generator.	Approximate floor space of Engine and Generator without Condenser and Pumps.
Westinghouse Air Brake Co., Wilmerding, Pa. 300 K.W. Westinghouse-Parsons Turbo-Alternator	75 square feet.
Vertical Side-by-Side Engine by D. Stewart & Co., Ltd. 16in. and 32in. by 30in. driving 300 K.W. Generator	209 square feet.
Ferranti Vertical Engine and 750 K.W. Generator. Manchester Corporation Electricity Works.	23¾ feet × 15 feet
Close Power Station, Newcastle-on-Tyne. One Turbine driving two Dynamos each of 500 K.W. capacity.	232 square feet.
Vertical Cross Compound Engine by D. Stewart & Co. Ltd. 35in. and 71in. by 42in. driving 1,500 K.W. Generator	650 square feet.
Central Station of the Hartford Electric Light Company, Hartford, Conn. U.S.A. 1,500 K.W.* Westinghouse-Parsons Turbine and Two Phase Alternator	291 square feet.
Three Cylinder Compound side-by-side Engine by D. Stewart & Co. Ltd. 38in., 58in. and 58in. by 54in. driving 2,000 K.W. Generator	1,230 square feet
Parsons Turbo-Alternator for New Power Station of Sheffield Corporation. 2,000 K.W.	37 feet × 9 feet.
Musgrave Vertical Engine driving 2,500 K.W. three phase Alternator at Glasgow Corporation Tramway Power Station	58 feet × 24 feet.
Six Cylinder Tandem Engine by D. Stewart & Co. Ltd. 32⅝in. by 54in. driving 3,000 K.W. Generator.	1,053 square feet.
Parsons Turbine driving two Alternators having combined output of 4,000 K.W.	400 square feet.
5,500 K.W. †) (rated Westinghouse-Parsons Turbo-Alternator for the Metropolitan District Railway Company.	724 square feet.

* Although rated at 1,500 K.W., this machine gave on a four hours test an average output of about 2,000 K.W.

† Ultimate capacity expected to much exceed this.

direct current turbo-generator and also condensing plant for 1,000 kilowatts.

At Forth Banks Power Station, Newcastle-on-Tyne, the total area of the engine-room containing a considerable number of turbo-electric generators (Parsons) with a total capacity of 3,000 kilowatts, is only 3,600 square feet.

At the power station of the Westinghouse Air-Brake Co., Wilmerding, Pa., U.S.A., the space occupied by three turbo-alternators (Westinghouse-Parsons) two 10HP exciter engines and generators, two pairs of condensers and air-pumps, and switchboard is 1,044 square feet, and a reference to Fig. 27. Plate V., will show that there is no crowding.

Reciprocating vertical steam engines suitable for driving electric generators could without doubt be made to occupy considerable less floor space than the most of them do at present. Whether or not this can be done without unduly handicapping them in other respects is a question which will no doubt be seriously tackled in the near future. To show the extent to which floor space can be cut down when necessary, I give in Table V. the length and breadth of two engines for torpedo craft for the U.S. Navy.

TABLE V.

Vessel.	Power of Engine	Overall length (Approximate.)	Overall breadth (Approximate.)
Torpedo boat	About 1,200 B.H.P.	10ft. 6in.	6ft. 6in.
Destroyer ..	About 3,200 B.H.P.	18ft. 9in.	7ft. 0in.

Condensers not included.

I do not say that these engines are suitable for power stations or factories, and the turbines mentioned in this paper must not be compared with them for marine propulsion, as no marine turbines are described or illustrated in this paper, nor do any occur in the tables.

The difference in the head room required by steam tubines and by vertical reciprocating steam engines is very great. Table VI. shows this.

TABLE VI.

Heights of Steam Turbines and Vertical Reciprocating Steam Engines.

Type of Engine.	Where situated.	Approximate B.H.P.	Extreme height in feet.
Ferranti high-speed Vertical reciprocating.	Manchester Corporation Electricity Works.	1,200	15½
Musgrave Vertical reciprocating.	Glasgow Corporation Tramway Power Station.	3,700	34
Westinghouse—Parsons Steam Turbine.	Wilmerding, U.S.A.	500	7¾
Parsons Steam Turbine.	Milan.	3,000	9

The ease with which an engine can be erected without the use of a crane is often an important consideration in determining what class of motor to adopt. The time required for erection is also in many cases an important factor. A steam turbine is undoubtedly light as a whole, and no part (or combination of parts to be moved as one part) is very heavy for the power. Further, except for the governor and steam pipe fittings, no part has to be raised any great distance from the ground. The heaviest part of the 1,000 K.W. turbo-generator shown in Figs. 21, 22 and 23, Plate IV, weighs 5¼ tons, and as this is the lower part of the turbine casing, its centre of gravity is but a short distance above the engine room floor.

The absence of vibration and of heavy foundations, the small floor space and head room, and the comparative ease of erection often enable a steam turbine to be placed in a situation in

which it would be difficult or impossible to instal a reciprocating engine.

The Forth Banks station of the Newcastle and District Electric Lighting Company is situated on the side of a hill, and the engine room is rather peculiarly placed. It would have been an expensive matter to have installed reciprocating engines in this station, but the Parsons' steam turbines, which alone are employed, suit the situation perfectly. There seems to be no reason why in power stations where ground is valuable steam turbines should not be arranged in tiers or storeys, one above the other. There would be no more inconvenience in doing this than there is at present with large vertical engines, where stairs and elevated platforms are a necessity. Each turbine would rest on a platform, and arrangements be made whereby each could be opened up if required, without disturbing the others.

Another arrangement which might be advisable where offices and other rooms (accumulator rooms for example) are required beside an electric power station, would be to place the turbines and electric generators all on one level, and place the offices and other rooms above (or in some cases below) the engine room, which could have a low roof, be mechanically ventilated, and be lighted from the sides. A travelling crane, where such is employed, could be arranged with its girders just clear of the roof on the one side and of the turbines on the other, the crane motors and gearing being fixed below the girders, and in such a position transversely as to clear the engines (and the steam pipes, if these are overhead). The crane is not to be used every day, and does not deserve too much consideration.

It appears to me that if we are to derive the full benefits from the employment of steam turbines in power stations, we must design these power stations to suit the engines; it is a waste of money to build a lion's cage for use as a dog kennel.

There is one thing which needs to be more carefully considered when employing steam turbines than when employing reciprocating engines and that is the exhaust pipes and condensers. I have already referred to the advantage of providing a good vacuum for a De Laval turbine. The velocities are not so great in a Parsons turbine; but a motor of this type can take far more advantage of a good vacuum than a reciprocating engine, and when we hear of some good result obtained by a Parsons turbine, we may be pretty sure that the pressure at the exhaust end of the turbine was extremely low. If we want to have good results from a Parsons steam turbine, we must therefore try to obtain a good vacuum in the condenser and make our exhaust pipe of large section and as short as possible. For example the exhaust pipe of the Parsons turbine driving the 1,000 K.W. generator shown in Figs. 21, 22 and 23, Plate IV, is 8ft. in diameter. Parsons turbines can however be run non-condensing, but with poorer results.

A good arrangement which saves space in the engine room and allows of a short exhaust pipe is to place the condenser immediately below the low pressure end of the turbine. Figs. 30 and 31 show a condenser so arranged to receive the exhaust steam from a 1,500 K.W. turbo-alternator of the Parsons type constructed by Messrs. Brown, Boverie & Co. T is the turbine, D the alternator, and L the exciter. E is the exhaust pipe

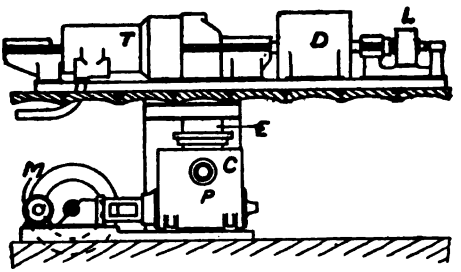

Fig. 30.

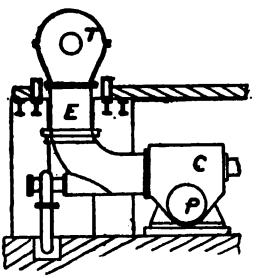

Fig. 31.

Arrangement of Turbine, Alternator and Condenser.

leading from the low pressure end of the turbine to the condenser C. M is the electric motor, which through gearing drives the air pump P.

The time in which a machine, not of a standard design, can be supplied by its makers reckoning from the date of receiving the order, depends more on the enterprise of the makers and the system employed at their works than on the nature of the machine; but at the same time some machines from their simplicity lend themselves more than others to rapid production and I believe that a steam turbine thus lends itself to more rapid production than any existing efficient form of reciprocating engine. A 3,000 HP steam turbine was completed by Messrs. C. A. Parsons & Co. in 1901, nine weeks after receiving the order for it.

It has been known for a long time that the use of superheated steam lowers the steam consumption of an engine; but it is only recently that superheating has been used to any great extent with steam engines. The obstacles to be overcome in using superheated steam with reciprocating engines are considerable. These difficulties do not however occur with the steam turbine. I do not say that with very high temperatures special precautions would not have to be taken with steam turbines; but, as far as superheating has been carried, I believe no difficulties have been encountered.

An important point to note in comparing condensing steam turbines with condensing reciprocating engines is that the exhaust steam from the turbine contains no grease and can therefore be returned to the boiler without filtering and without fear of disastrous results.

As regards cost of up-keep, there are no large turbines which have been running for long; but experience with smaller sizes of Parsons turbines seems to show that the wear on the blades

by the steam is practically zero. (The blades must of course never be allowed to rub against each other). Bearings wear out in time as might be expected (but not rapidly) and have to be replaced. The experience at the Forth Banks Station at Newcastle where Parsons turbines have been running for more than 6 years, is that the cost of up-keep is trifling. Of course like any other machine, a steam turbine must be intelligently cared for.

TABLE VII.

Steam Turbines compared with large Gas Engines as regards floor space and weight.

Nature of Motor.	Type.	B.H.P.	Approx. over all length in feet.	Approx. over all breadth in feet.	Approx. Weight including flywheel, if any, in tons.
Gas Engine	Crossley	120	12	9	—
Steam Turbine	De Laval	150	11 Includes two broad face driving pulleys	4⅓	4¾
Steam Turbine	De Laval	300	15 Includes two broad face driving pulleys	6½	8
Gas Engine	Körting	400	30	18	50
Gas Engine	Gasmotoren-Fabrik Deutz.	500	44	18¾	119
Gas Engine	Cockerill Single Cylinder	600	—	—	125
Gas Engine	Körting	700	41	23	127
Gas Engine	Körting	1,000	49	29	190
Steam Turbine	Parsons Compound	3,000	29½	8¾	35

As large gas engines are now coming into use for the economical production of large quantities of mechanical energy, it may be interesting to refer to them as rivals of the steam turbine. The large gas engine has come to stay; in my opinion there is no doubt about that. It does not follow however that it will displace the steam engine in even the majority of cases in which the latter is used. This is not a discussion on the relative merits of steam and gas engines, but I might mention that in one respect the large gas engine as now constructed can never rival a steam engine of the turbine type. I refer to smallness of size for a given power. Table VII. shows this well.

There will probably be a fierce contest in the near future between the large steam turbine and the large gas engine for use in big power stations, I am not going to prophesy which will have the victory. Time will show which is the fittest for the work. This however is an age of combines, and the fight between the turbine and the gas engine may possibly end in the two being merged into one.

DISCUSSION.

The CHAIRMAN (Mr. E. G. Constantine) said that the very excellent paper to which they had just listened was now open for discussion, and as he believed there were several gentlemen present who were interested in the subject of steam turbines, they would all be very pleased to hear any remarks they had to make on the subject.

Mr. ALFRED SAXON congratulated Mr. Neilson on the paper presented to them, which had shewn that there must have been a considerable amount of investigation on the author's part

to have enabled him to provide such valuable information as that contained in the paper.

He, however, desired to take advantage of the invitation offered, where the author stated that he hoped the question of rope speeds and speed of rotation of shafting would be dealt with in the discussion, by members better qualified than himself to speak on this subject. He noticed that Mr. Neilson had cited as an example a 600 BHP gearless steam turbine running at 2,000 revolutions per minute, with which he desired to drive several lines of shafting by means of ropes.

He thought that the author had assumed a very extraordinary proposition by supposing that a satisfactory and practical rope speed of 4,000ft. per minute could be obtained from 1in. and $\frac{3}{4}$in. ropes, with 8in. pulleys on the turbine shaft and 64in. pulleys on the driven shaft; if Mr. Neilson had looked up some authorities on rope driving he would have found it laid down as a very necessary condition that the pulley should be 30 times the diameter of the rope, so that instead of the 8in. pulley named, it would require at least a 2ft. 6in. pulley, which would bring about a rope speed of 15,600ft. per minute; or if a $\frac{3}{4}$in. rope was used, a rope speed of about 11,700ft. per minute, and the highest velocity he could find tabulated for rope speeds was up to 7,000ft. per minute. He could, therefore, only think that either the turbine speed was altogether too high for the purpose, or the scheme was impracticable, as it would be altogether unsatisfactory to attempt rope driving on the lines stated in the paper.

As regards the gearing down being a less costly matter than the gearing up, he did not think that rope driving would be cheapened on those lines, because if they were to take a corresponding size of driven pulley from the 2ft. 6in. pulley, they would require driven pulleys 20ft. diameter.

Mr. BARKER (visitor) remarked that he was probably, with one exception, the oldest turbine engineer in the world, having been connected with them since 1893, or for 9½ consecutive years. He had been employed at Messrs. Parsons, and had seen how that firm's engines had grown from the toy to their present dimensions. As regards the weight of the Turbines mentioned by Mr. Neilson, he thought that a very striking example to illustrate this was in the Bloom Street works, where engines of 8,000 HP weighed only 400 tons.

He was very much in favour of turbines being used instead of reciprocating engines, because the repairs were very small, and the former did not require repairing as often as the latter, also there was a great saving in the coal bill.

In conclusion, he observed that he had the honour to undertake the delivery of the nine weeks' engine stated in the paper, and although the contract was for three months delivery, yet for some reason or other the buyers could not take it then and it had to remain in the makers' workshop five months.

He had great hopes of the gas turbines, and thought the time would not be far distant when the gas turbine would not be touched by anything for economy and a cheap tool.

Mr. REGENBOGEN (visitor) observed that he was from the Westinghouse Co., and he thought that the reason steam turbines were not used as much was on account of the friction caused by the high speed.

On referring to the difference in floor space, between steam turbines and steam engines, he said that at the Westinghouse the floor space was one quarter of a square foot per kilowatt.

Another advantage of the steam turbine was that they did not require any lubrication inside the turbine.

As regards gas turbines he might state that the Westinghouse Co., gas engine of 1,600 HP, having two cylinders, weighed only 190 tons.

Mr. A. WALSH asked whether a turbine could work where the full load was always on, that is to say, where the full load had to be moved at the first turn, because if it would not do this he was afraid that steam turbines would not do for mill work. As he understood at present he thought they had to get up a certain speed similar to motor cars before they would start.

Mr. KONRAD ANDERSSON (visitor) noticed that there had been a question asked regarding the possibility of using belts or ropes for the turbine; if they would look at Plate 2, Fig. 6, there was shown a 225 B.H.P. De Laval turbine which had been constructed for a mill, and was very suitable for belts or ropes.

In reference to the starting of the turbine with the full load always on, mentioned by Mr. Walsh, in his opinion he thought that although it took a great deal of power to start in this way, yet he was under the impression that it was quite possible for a turbine to start a mill with the full load on similar to the steam engine.

Mr. A. V. COSTER agreed with Mr. Neilson that it was probable in the near future that the turbine and gas engine would come into combination. Eight years ago he patented a gas turbine, which drew in gas and air at one end, at the centre the charge was mixed after passing automatic valves, and then electrically exploded and expanding through fixed and movable vanes on its way to the exhaust.

He also agreed with the author that gas engines had come to stay, and there was no doubt that they were coming more and more into prominence every year. The running of gas engines had been mentioned by a gentleman who stated that one ran for three weeks without stopping, but he might mention that at Brunner, Mond's, a 500 HP engine had run four months without a stop.

He thought that the most important feature regarding these engines was the consumption of coal used by each, and the one which produced the greatest economy would win the day.

Mr. W. INGHAM observed that in the paper there was a diagram shewing the steam consumption, and that Mr. Neilson had stated that one of the turbines mentioned in the paper gave a better result than the reciprocating engine when run at full speed. He would just like to mention that the heavier the load put on, the higher the horse power and the less the steam consumption.

Mr. W. A. TRITTON said that during his experience with turbines he found that they gave very little trouble themselves, but he had experienced some difficulty with the generating plant, and in his opinion the greatest fault appeared to be with the alternator bearings; possibly, this was due to not having had the attention from engineers which they ought to have.

The CHAIRMAN (Mr. E. G. Constantine) said that he was very sorry to have to draw the discussion to a close, but time and tide waited for no man.

He thought it was his duty to congratulate Mr. Neilson on his excellent production that evening, and he ventured to say that it would prove to be of immense value.

He was of opinion that steam turbines would occupy the attention of engineers for some time to come, but must confess that he was rather disappointed that the reciprocating engineers had not come forward more prominently with their engines. He thought, however, that there remained a great deal to be done before the steam turbine would prove to be a very serious rival for mill driving, etc. At the same time if he were sitting in judgment between the two engines for the future, his verdict

would be towards favouring the steam turbine, both as regards its suitability and its efficiency for many purposes.

He however did not intend to criticise the subject in detail, and would therefore ask Mr. Neilson to respond very briefly to the points raised in the discussion, and to give a more elaborate reply for embodying in the transactions.

He would just like to say in conclusion to the visitors present that they were always pleased to see gentlemen who were willing to give their experiences.

He proposed a hearty vote of thanks to the author for the excellent paper, which was carried with acclamation.

Mr. NEILSON, in responding, said that he thanked the members very much for the way in which his paper had been received. Before replying to the discussion he wished to express his thanks to those gentlemen who had assisted him by giving and lending him materials for the paper.

He thanked Mr. Saxon for his remarks on driving pulleys, which were very interesting. Mr. Saxon was an authority on rope driving and his observations were therefore valuable, and the statements he (Mr. Saxon) had made were probably correct. Driving by electric power had many advantages, and was being adopted by several firms, amongst which he might mention Messrs. Greenwood & Batley, Ltd., of Leeds, who had their turbine shop wholly driven by electric motors. These motors received their current from dynamos, driven by De Laval steam turbines.

Mr. Barker's remarks were very interesting, and were a valuable supplement to his paper. He had had to limit his paper to certain things, and therefore could not put in every detail or mention all the points that he would have liked to.

He thought one of the advantages which the turbine had over the reciprocating engine was that with the latter they could not

expand right down to a good vacuum, whereas with the former they could expand to the lowest pressure.

As regards the question of Mr. Walsh as to whether the steam turbine would be able to start a mill with the full load on at the first turn, he was of opinion that there would not be the slightest difficulty in doing this, but it would possibly take it a little time to get up normal speed.

Mr. Barker, Mr. Coster and Mr. Tritton had referred to gas turbines, which subject was very interesting, and he would have liked to have gone into it, but as he had previously remarked, the length of his paper was necessarily limited, and he had confined it to Steam Turbines.

He thought he had referred to all the points raised in the discussion, but if not, and if he noticed his omission, he would write a reply for embodying in the transactions.

5 Plates follow illustrating this Paper.

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UNIV. OF MICH.

OR POWER STATIONS AND FACTORIES.

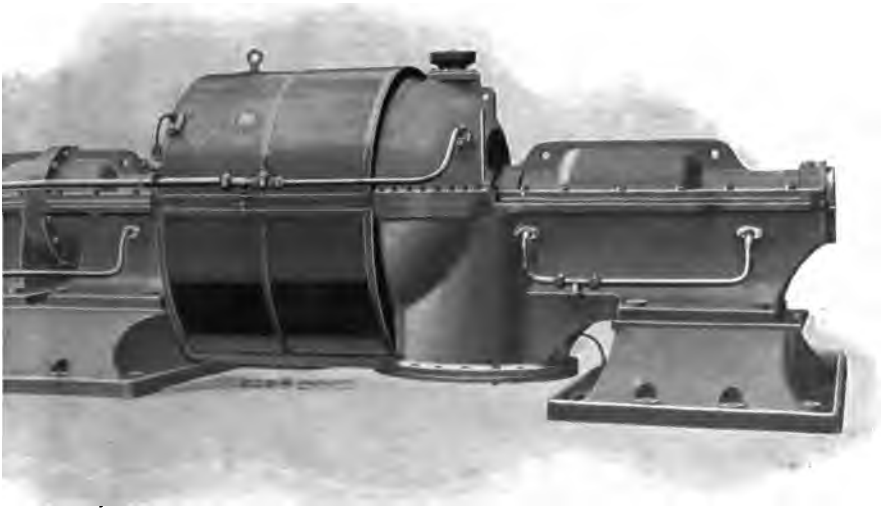
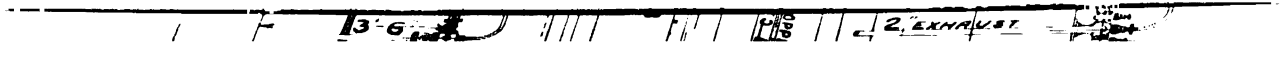


Fig. 19.

P. Two-Cylinder Parsons Turbine.

UNIV. OF MICH.



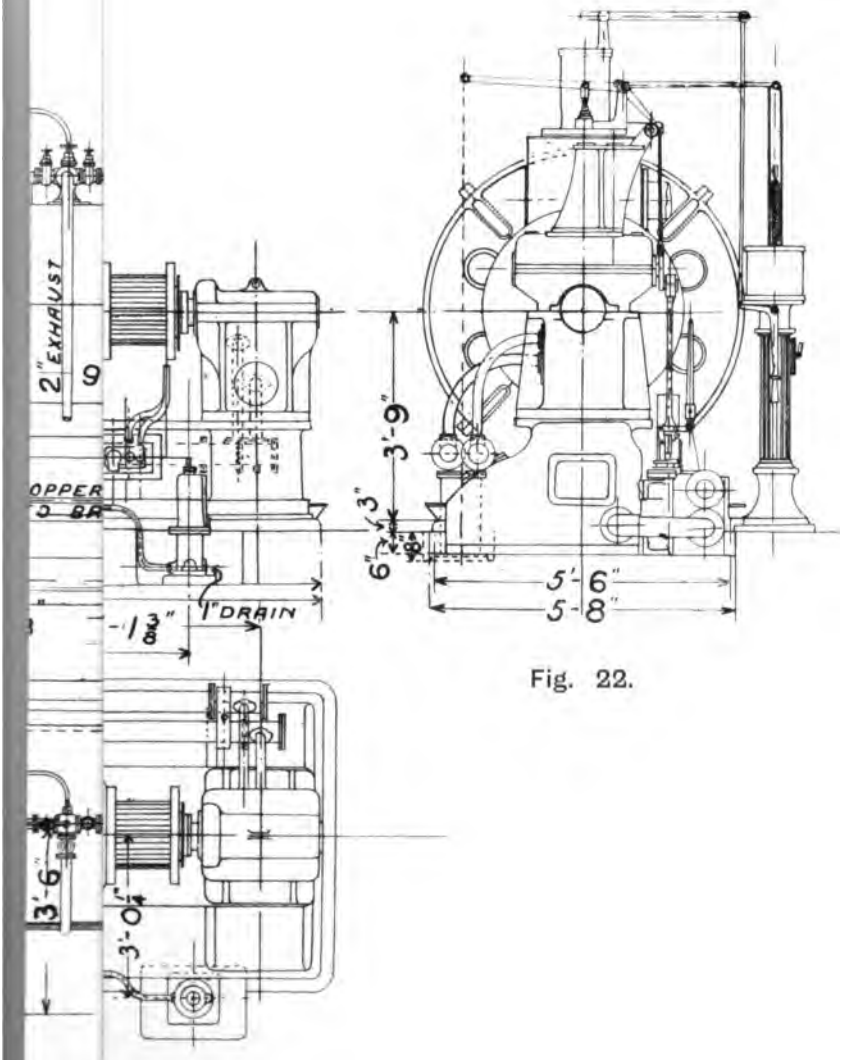


Fig. 22.

Company.

ONF
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GAS ENGINES,
WITH RECENT IMPROVEMENTS.

READ SATURDAY, 28TH FEBRUARY, 1903,

BY

Mr. JAS. ATKINSON, M.I.Mech.E.,

MANCHESTER.

In 1894 the author had the honour of reading a paper before this Association on the same subject, in which he had an opportunity of bringing before your notice some of the advances which had up to that time been effected in the improvements of gas engines. In the interval between then and now the gas engine has been developing at a rapid rate and the time is fast approaching when the steam engine will have to take a secondary position as a power producer.

At the present time every engineer who has considered the question agrees that a gas engine with a suitable gas producer will generate power at a cheaper rate than any steam engine and steam boiler ever made, it might almost be said that ever can be made.

The majority of our best engineers during the last 50 years have devoted their energies to the steam engine, but all their efforts with increased pressures, multiple expansion and superheating fail to enable it to compete in economy with the gas engine; though, until recently, the latter has only had a small minority of people who have really given their serious efforts and time to its development.

Increase of size and increased compression pressures are the most marked feature in the present development of gas engines,

These increases have necessitated modifications in certain parts and this paper will mainly deal with these modifications.

Strains due to increased heat, increased pressures and the operation of large valves have gone beyond the capabilities of older designs, and new features are necessary to enable these larger modern engines to stand. In this connection it is necessary to discriminate and to consider the particular conditions under which the engines are to work. For instance some very large engines have been made and put to work, chiefly on the continent, some of them mainly constructed on the lines of engines as made in this country 10 years ago. Such engines would not work for an hour with ordinary illuminating gas at anything like full load. They are working with gas of low calorific value, consequently at cylinder temperatures considerably below those common to even small engines in general use; also when driven by blast furnace gas, there is a greatly reduced risk of pre-ignition, owing to there only being, say, 2 % of hydrogen in the gas. In such engines therefore, it is scarcely necessary to take the precautions which are absolutely essential in large engines working with richer gas or gas containing a larger proportion of hydrogen, such as ordinary town's gas, producer gas or water gas.

Figs. 1, 2, and 3, Plate I, show the cylinder end of large engines as now made by Messrs. Crossley Brothers, Limited, having improvements in the method of constructing the main casting, watered exhaust valve, watered piston, and compensating piston on the exhaust valve. It will be seen that the exhaust valve box is now a separate casting, thus removing one of the main causes of the fractured breech ends, which may be said to have been one of the chief sources of trouble with large engines.

The inner metal surrounding the combustion chamber is cast quite free from the outside metal excepting where joined to the

outer metal by the branches to the exhaust valve at the bottom and to the admission valve on one side. A casting is thus obtained which is free from all casting strains. Lugs are cast in the inner and outer metals which are drilled, tapped and have screwed stays inserted binding the two together; an enlarged view of these studs and lugs being given in Fig. 4, Plate I. A large opening is formed at the back fitted with a thin cover, this gives ample access for cleaning; the large opening tends to the soundness of the casting, also in case of frost freezing the water in the jacket, the plate would probably give way, and thus save the main casting. The metal surrounding the combustion chamber can be thin, as the strength is thoroughly reinforced by ribs and by the connections to the outer metal. It is very satisfactory to note that since this mode of construction was adopted there has never been a case of a single breech end giving way, though there are a considerable number of engines fitted with these running, in some instances working night and day on very heavy constant loads. The author believes that it would have been impossible to have constructed such engines with the older types of breech ends without having constant breakdowns from fractures.

Increased size has led to the necessity of circulating water through the exhaust valve. Fig. 5, Plate II, shows the method now adopted, and is self-explanatory. The main piston also has to have a watered end, so that in these large cylinders there is no part exposed to the hot working fluid which has not got water on the other side, with the exception of the head of the inlet valve which is kept cool by the admission of each fresh charge. This appears to be the only satisfactory method by which pre-ignition can be prevented, though some of the continental makers place the admission valve head facing the exhaust valve head in a narrow port or passage communicating with the combustion chamber;

the incoming fresh charges thus keep both the admission valve and the exhaust valve cool; this arrangement has something to recommend it but it cannot be so satisfactory as it makes a combustion chamber which is both uneconomical and very difficult to clean out without removing the piston, a somewhat heavy job with a large engine. In the breech end shown in the illustrations, it will be seen that by removing the air valve block, the whole of the interior can be examined and cleaned, also that any dirt, burnt oil or scale drops out through the exhaust valve passage. In larger engines it is an advantage to be able to slide the exhaust valve out horizontally as it is of considerable weight.

When it is realized that large engines frequently have a pressure of 50 lbs. per square inch in the cylinder when the exhaust value commences to be opened, and that a valve of considerable size is necessary, it will be understood what a great improvement it is to use a compensating piston to relieve this load, which often runs into tons. Exhaust valves in large engines have to be operated, say, perhaps 60 times a minute usually by means of a cam on the side shaft, roller and lever; if the heavy load is not relieved the cam wears very fast just at the point of opening, and once it gets out of shape the trouble increases; the same applies to the gear wheels driving the side shaft which also wear at a rapid rate at this one place, thus intensifying the evil.

In the paper read before you in 1894 an arrangement was described for scavenging out the burnt gases, and it has proved to be a satisfactory arrangement, being now at work on some hundreds of engines. At the present time there is not so much advantage to be derived from scavenging, as compression pressures having gone up, combustion chambers are reduced in volume, and there is a smaller volume of residual gases to remove. The possible saving in gas is thus not so great, nor

can as large an increase in power be obtained; nevertheless, there are many instances in which it is desirable to use the long exhaust pipe and special setting of cams. One difficulty which cropped up in connection with this arrangement was an unexpected one, viz.: the noise of the exhaust increased and in many instances it has been necessary to arrange for special silencing arrangements which would not otherwise have been necessary; in this connection, in some instances, the noise of the exhaust has been most successfully reduced to practical silence by putting the ordinary silencers in a pit filled with large stones and having an outlet from this pit.

The use of large engines for driving directly coupled dynamos for various purposes is rapidly coming to the front. In some instances when used, say, for electro-chemical processes, large engines are now running night and day on their full output; it is needless to say that this means a most severe and exhaustive test of every part of the engine, a year's run on such a duty being at least equal to three years' ordinary work, and it is most satisfactory to be able to say that there are now many such instances. In one case an engine of 400 HP ran 7 months continuously without being stopped. There are instances of large engines running 97% of the total hours in the year, the 3% including stoppages due to all causes either affecting the engine or the electrical part of the combination. In another case four engines are in constant day and night work in one engine house each on a load of 800 kilowatts.

The requirements of the electrician for steadiness in running and accurate governing have now got far beyond anything anticipated some years ago, but as in most mechanical matters, when the need arises and is sufficiently emphasized the solution is found.

For very accurate regularity of turning and with large engines of the four stroke or "Otto" cycle it is desirable to use four

cylinders in any suitable combination and to use an impulse automatically regulated by the governor. Such an engine will if properly constructed give almost perfect regularity, and it is interesting to note that the inertia of the reciprocating parts, in many instances, just about compensates for the high initial pressure of each ignition and levels up the falling pressure towards the end of the stroke, giving a very uniform turning moment to the crank pin. It is also very convenient that in gas engine design it is not necessary to have a very powerful governor, so that the full range of power can be controlled without much variation in speed between full load and no load. In two engines recently tested by the author this maximum variation did not exceed $\frac{3}{4}$ of 1 %.

Figs. 6, 7, 8, and 9, Plate I, show an arrangement of the automatic cut off gear. It consists of a multiported cylindrical valve sliding inside the casing of the admission valve. This valve is driven by a small eccentric through a lever which has a moveable fulcrum controlled by the govenor through (in this instance) right and left hand threads. The pitch of the threads is such that any thrust on the fulcrum will barely tend to move the nut on the right and left handed threads, but as there is a push and a pull for each admission, the governor requires scarcely any power to enable it to move the nut one way or the other at these times; consequently, it can take up a new position to suit the power requirements without being required to exert anything beyond an extremely small amount of effort; owing to this the governor itself can be made almost isochronous.

Fig. 10, is a copy of an indicator diagram taken from an engine fitted with one of these cut off gears, and Fig. 11, is a diagram taken with a stop in the indicator, and with a weak spring showing the effect of the varying cut off; the point where the compression crosses the atmospheric line shows the proportionate volumes of the varying charges. The definite cut-

off is preferable to a throttling governor which has been used in some gas engines, as the latter method causes considerable loss in the power, especially at light loads, because the suction line runs very much below the atmospheric line all the way, the compression line returning much closer to this line, thus

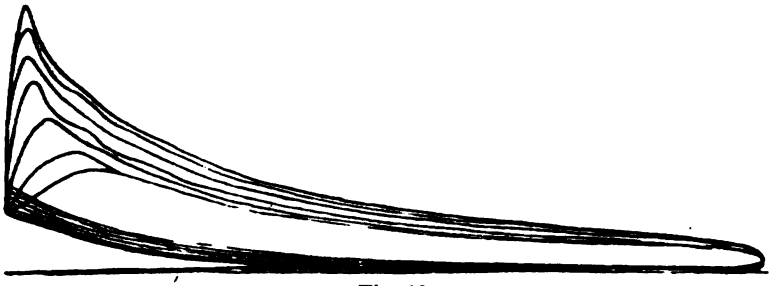

Fig. 10.

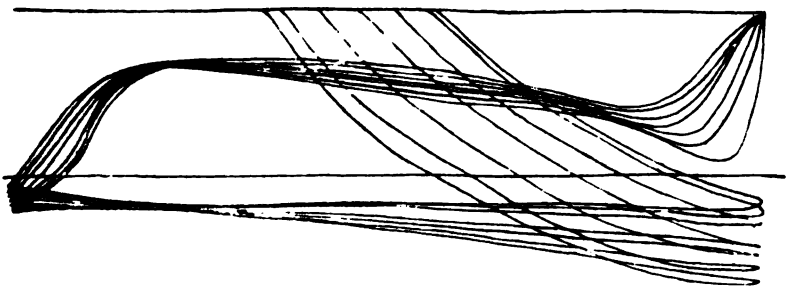

Fig. 11.

enclosing a considerable area of the diagram representing negative work. It will be seen that the return compression line returns on the suction line almost up to the point of the cut off.

In tests which have been made with this gear it has been found that with the gear the gas consumption is about the same as with a hit and miss governed engine from full load down to nearly half load, but that below half load the hit and miss governor has the advantage; if the automatic gear is adjusted to give very light impulses so as to run the engine without load, and without missing, the hit and miss governing is from two to

three times more economical. For these reasons the gear is so arranged that it may be adjusted to give hit and miss governing at and below any desired load.

The hot tube ignition still continues to hold its own, and when suitable gas is available it is impossible to beat it for stationary engines. The metal tubes however have almost entirely disappeared, and long life porcelain tubes are now universal. When two tubes are fitted to an engine, each with its own chimney and flame, its own separate ignition valve and gear with means of shutting either off so as to replace a burst tube without stopping, it looks almost as if there were not much chance of development or improvement in this direction.

There are numerous instances however where a suitable gas supply is not available and electric ignition has to be used. For this purpose batteries of any kind are an intolerable nuisance; they may possibly be desirable for motor car work, but unless a constant supply of electricity is on tap small dynamo machines are undoubtedly the best. These are usually constructed with permanent magnets, arranged to give a substantial spark of equal intensity either at starting or during running at any speed, have means for adjusting the timing of this spark whilst at work and as made by any good firm are a good, durable, serviceable job. Still, the double tube ignition is undoubtedly the best when it can be used. It is however difficult in some cases to persuade purchasers in their own interests to have tube ignition, as they frequently insist on having electric ignition.

Gas producers for making suitable gas out of almost any kind of fuel have made in recent years very great progress and thus added impetus to gas engines both large and small. The gas engine user can now be independent of the gas works, and combined installations of gas engines and gas plants are now common all over the world. Dowson gas has been in satisfactory use for a number of years, but the fuel used was limited

to anthracite or coke. There are now many makers of small simple plants which can be put down almost anywhere and relied on to do their work admirably, using anthracite coal or coke, which in a general way may be said to be the best fuel for small powers.

For larger powers, plants can now be obtained using bituminous coal of common slack quality. The engines driving Messrs. Crossley Brothers' works have been working with the gas from such a plant for some two years. When first the plant was erected, there was a good deal of trouble caused by tar passing away with the gas and interfering with the proper action of the valves in the engines, and this tar difficulty still exists in some bituminous gas plants working. In the above instance, however, modifications in the plant and the addition of a special "tar separator" completely overcame the difficulty, and the gas is practically as clean as that supplied by the Manchester Corporation so far as regards any impurities which can prejudicially affect gas engines.

As the "tar separator" is quite an important part of this bituminous coal plant, it is illustrated in Figs. 12 and 18, Plate III. It consists of a disc which is revolved at a very high speed, and has on each side a number of radial blades almost fitting the casing as shown. The gas comes in at the centre on one side, and passes outwards on this side of the disc, being put into circular motion which gradually increases to an extremely high speed as it turns round the edge of the disc; it then passes inwards at a reducing speed till it leaves in the centre on the other side. The gas to be cleaned is either loaded with moisture as it comes from the cooling towers, or a little water may be admitted with it; this water, and any tar, dust or other impurities are thrown outwards at the edge of the disc and carried round till they escape at the outlet at the bottom. The great advantage of the separator

is that though it takes a good deal of power to put the gas up to such a high circular speed the bulk of this power is returned to the disc as the gas slows down in again approaching the centre on the outlet side.

Both anthracite and bituminous gas plants can be operated so as to make the gas just as fast as it may be required without requiring any gas holder, thus doing away with a cumbersome and expensive part.

In a large works the motive power for any particular shop can be obtained from an engine or engines in the shop itself. It does not cost anything beyond the first cost of the gas mains to carry the gas to the engines, so that a gas producing plant, distributing mains and isolated engines where required give ideal conditions, and each lb. of common slack will give a horse power hour in any desired position.

The use of the gas from ordinary blast furnaces in gas engines is a burning question for the present time. English manufacturers of gas engines have been frequently twitted with allowing the foreigner to get ahead in this departure, but it may be that it is the English proprietors of blast furnaces who are mainly to blame. Gas engines were running in England with blast furnace gas, and the economy to be thereby obtained was publicly preached in England before the question was taken up on the continent, but the manufacturers of iron did not move. Even at the present time some very large steam driven blowing engines are being constructed in face of the fact that they will require five or six times the amount of gas (burned under the steam boilers) supplying them with steam that would have sufficed in gas driven blowing engines.

To use blast furnace gas by burning it under steam boilers is a waste which is sure to be stopped before long. In a few years time it is probable that only the blast furnaces equipped

with gas engines will be able to make iron profitably. It is reasonably calculated that the use of gas engines with blast furnaces will reduce the cost of production by 5s. to 8s. per ton.

There is one feature of the gas engine which does not develop and that is compounding. An engineer accustomed to steam engines has been so used to the enormous advantages gained in compounding steam engines that he cannot stand opening the exhaust of a gas engine into the atmosphere at 40lbs. per square inch. In 1884 the author patented and constructed a compound gas engine; the ordinary cylinder was one in which an impulse every revolution was made and a compound cylinder was fixed at the back, the cylinder, being axially in line with each other. The piston of the compound cylinder was made very light, and was connected by light side rods to the crosshead of the engine. The whole arrangement worked perfectly satisfactorily, and was kept running for over a year. There was a slight gain per indicated HP, and a still less gain per effective HP, but nothing to justify the extra cost beyond the fact that to some extent the engine was double acting, giving out power twice per revolution, and the exhaust was very quiet. Ultimately the compound cylinder was taken off, and the engine subsequently worked in the ordinary manner.

In 1899 Messrs. Crossley Brothers constructed a compound gas engine having three vertical cylinders, two high pressure cylinders working on the Otto or four stroke cycle on the outsides, with a compound cylinder in the middle, the two high pressure cranks being in line with each other and opposite to the low pressure crank. The working impulses took place alternately in the high pressure cylinders, and alternately exhausted into the low pressure cylinder, which thus gave out power once per revolution; as the high pressure cylinders also between them gave out power during the other strokes, the engine had two power strokes per revolution. The connecting passages between

the cylinders were short, the fluid was perfectly controlled by a suitable piston valve, and the engine ran quite satisfactorily. Diagrams from this engine are shown in Figs. 14, 15, and 16. Again, however, "the game was not worth the candle." The economy was very slight, and there was very little chance of the public paying for the increased cost, which, of course, would be considerable. It looks as if any increased expansion beyond the original volume of the charge can only be got satisfactorily in the one cylinder, and even if so obtained it is at an increased capital cost per unit of power.

Single cycle engines, which give a working stroke with a single acting cylinder once per revolution, are again coming to the front. The author between the years 1878 and 1898 made several types of such engines, the details of which most of the members will recollect. In each case they were single cycle engines but probably before their time, as the public demanded Otto type engines, and would have nothing but Otto type engines.

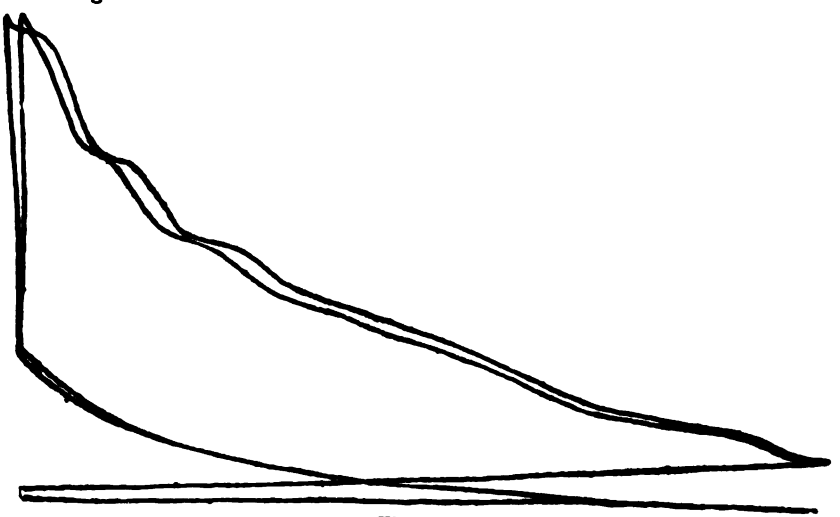

Fig. 14.

Compound Engine. Left-hand Cylinder. Scale 120lbs. = 1 inch.

In the Körting engine a single cycle engine is made double acting, so that it gives two working strokes per revolution like a single cylinder steam engine. This requires a piston rod passing into one of the combustion chambers with the attendant loss of about 9 % in economy, and 9 % in power at this end, or half as much for the whole engine. This loss is shown by the published particulars, and is confirmed by there being a similar though greater loss in the double acting Griffin engine as tested at the

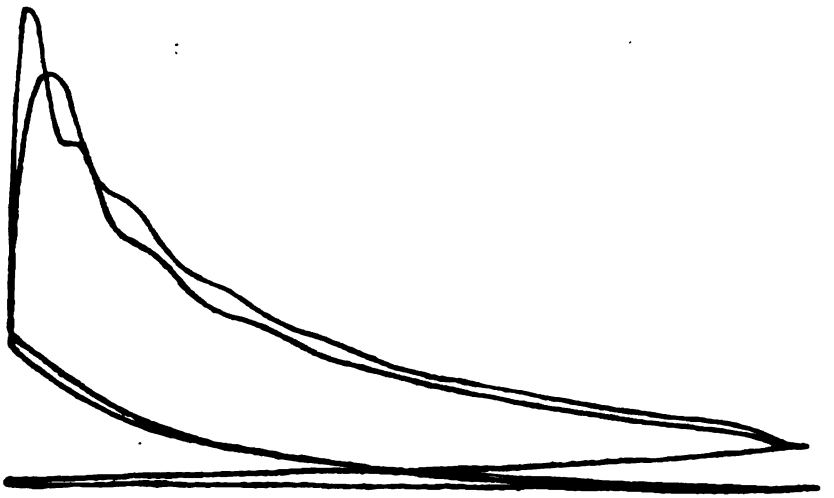

Fig. 15.
Compound Engine. Right-hand Cylinder. Scale 120lbs. = 1 inch.

Fig. 16.
Compound Engine. Low Pressure Cylinder. Scale 20lbs. = 1 inch.

Society of Arts trials. It does not however follow that it is not good practice to incur this loss for the sake of other advantages. Large gas engines are at the best a compromise, and when working with blast furnace gas, or cheap producer gas, the extra cost for gas is very slight. In very large engines the cooling surface of a piston rod or some similar kind of surface may be necessary to prevent pre-ignition.

It is difficult to forsee what the developments in gas engines in the immediate future will be, but it is certain that the purposes for which they will be used will be enormously extended, and their use greatly increased even beyond the great numbers now being manufactured largely owing to the increased use of power gas. It is possible that special requirements will cause special developments, as is to some extent illustrated in the types of engine now so largely made for motor car purposes, which require to run at very high speeds and to be as light as possible. Some of these engines weigh only 10lbs. per horse power—a truly marvellous performance. Developments are probable, by making double cylinder double acting Otto type engines, tandem fashion, which can be run at nearly double the speed at which single cycle engines can be run, and are also more economical, being no dearer than a single cycle double acting engine which requires large air and gas pumps; and three cylinder type, double and single acting engines of vertical construction, for which there seems to be a demand.

The writer feels that some apology is due to the members for the somewhat disjointed nature of this paper, but he would remind them that developments in gas engines are now chiefly in separate details, more or less independent of each other, and also that the above descriptions are mainly from personal experience in connection with the author's firm.

DISCUSSION.

The PRESIDENT (Mr. E. G. Constantine) remarked that they had heard a good paper, which was what they had expected from Mr. Atkinson, and therefore he hoped it would result in a useful discussion.

Mr. A. R. BELLAMY said he was sure that they were all much obliged to the author for his interesting paper, especially those members who were directly connected with the gas engine trade.

He thought they would all remember the last paper read by Mr. Atkinson, with its startling announcement of economy that was to be obtained by an ingenious arrangement of "scavenging" the combustion chamber with air, through the energy of the exhaust gases passing down a long pipe. It, however, came as a surprise to learn from the paper read that evening, that one difficulty which cropped up in connection with this arrangement was an unexpected one, viz: "the noise of the exhaust increased and in many instances it has been necessary to arrange for special silencing arrangements, etc." Let them compare this language with the author's former paper which states that "It is satisfactory to note that silencers such as 'Justices' packed with gravel, or quietening chambers such as commonly used do not affect the result any more than they do with ordinary engines." Now "Justices" silencer is a box or vessel partly or entirely filled with small stones, and the passage of the exhaust through these stones effectively deadens the noise of the exhaust. Perhaps, therefore, the author will explain the two statements, which he had quoted, and also say how many such scavenger engines were manufactured last year? He

asked this question because it was commonly reported in the trade that scavenging, as described in the author's last paper, was as dead as a door nail. It might be that his remarks on compression threw some light on this matter, because they were informed that at the present time there was not much advantage to be derived from "scavenging, as compression pressures have gone up compression chambers are reduced in volume and there is a smaller volume of residual gases to remove."

It would be interesting to learn how much the compression had gone up, because in 1894 the author gave the compression with coal gas at about 80lbs. and with fuel gas 90lbs. An increase of 80lbs. would only reduce the cubical capacity of the combustion chamber about 20%. Might there not be too much supposition in that last paper. He was afraid that the author had yielded perhaps a little too readily to the temptation of making known the discovery, and had not faced the difficulties which in detail the invention involved. Engineering is an exact science. Science and an ounce of fact was worth a ton of theory.

He agreed generally with the author's remarks on the economy of gas engines *versus* steam engines, but he would not like to be responsible for the statement that the time was fast approaching when the steam engine would have to take a secondary position, especially when they took into consideration the enormous use of steam engines for marine purposes, and the great stimulus that would be given the steam engine by the rotary engine. As regards the exhaust valve box now being a separate casting, he might add that this has been common practice for many years, and the exhaust valve seat was cast with cylinder end to do away with the joint, which was a source of trouble.

Dealing with the design of cylinder end, the author stated that the combustion chamber was joined to the outer metal

at two points in the same plane and at right angles, and he would like to know how it could be said that the casting was free from all casting strains. Would it not be better to have the combustion chamber quite separate from the outer casing? He thought the method of staying the inner and outer metals by means of long screwed studs was open to objection, because they had to depend upon the fit of the thread, and there was also the question of corrosion, inasmuch as the studs were exposed to the action of circulating water. He was also of opinion that it would be better if the combustion chamber was secured more directly to the outer flange, which is bolted to cylinder. He knew of instances where large engines were working satisfactorily with cylinder ends in which the combustion chamber was cast with the outer casing, and in one case of a large double cylinder engine working continuously under a heavy load, one cylinder was fitted with the cylinder cast in one piece, whilst the other cylinder had a cylinder end with the combustion chamber cast almost separate from the outer casing. This engine had been at work for a considerable period, and neither design of cylinder end, so far, had given any trouble.

Referring to the author's remarks on exhaust valves, it had been the practice for many years to circulate water through the head of the valve, and it is in general use at present on comparatively small engines. Exception might be taken to the position of this valve, because of the long passage from the combustion chamber to the head of this valve, and also because the valve was horizontal. He observed that it was generally recognised that the best design of combustion chamber was the one without passages, and the best arrangement was to have this type of valve working vertically. The author also drew attention to the uneconomical design of the combustion chamber adopted by the Continental makers, and ascribed this to the

port or passage in which were placed the admission valve and exhaust valve heads. An advantage was claimed for the exhaust valve being horizontal because it could slide out. Bearing in mind that this valve was right under the cylinder and generally below the floor line, could it be said to be as easily handled as a light vertical valve, which can be drawn out from the top of cylinder end.

The arrangement shewn by the author of balancing the exhaust valve was open to objection, on account of the compensating piston being exposed to the explosion, which was liable to fasten it, and there would be a serious escape of pressure past the piston into the exhaust pipe through a passage which might appear to have been provided for this purpose. Would it not be better to use the simple valve and so construct the cam to open it slowly, in order to distribute the strain over a greater period? In the case of very large engines then use two valves.

As regards the question of governing, it was now generally recognised that some form of throttle gear was necessary when gas engines were directly coupled to dynamos. Whilst agreeing generally with the author's remarks on this point, he thought attention should be directed to the somewhat complicated gear described. The light spring diagram shews that this was not a quick cut-off. Some Continental makers had used the cut-off gear, but had now discarded it for a much simpler arrangement, which throttles both the air and the gas.

From experiments which had been made with the two arrangements, viz: "cut-off versus throttle," the question of economy appeared doubtful, and it would be interesting to learn whether the author had made any experiments with the two systems on the same engine, which would enable him to state whether there is a considerable loss in the power when using the throttling system. ?

He was much surprised to read that "It is impossible to beat hot tube ignition for stationary engines," as one of the largest gas engine makers in the world had practically abandoned tube ignition in favour of magnetic electric ignition for all sizes. Experience had already proved that with electric ignition the starting of large gas engines was easier and more certain, and the ignitions more regular, especially when using "poor" gas. The electric ignition gear gets rid of the timing valve, as well as the ignition tube, which had always been troublesome. He knew of several instances where tube ignition had been taken off gas engines in this country and magnetic electric gas substituted.

Whilst not wishing to make such positive statements as Mr. Atkinson had done, yet he ventured to think that when the author read another paper on gas engines before the Association that his views about the hot tube ignition would be considerably modified. He thought that purchasers had a way of finding out what was best, and as a rule could be left to look after their own interests. In his opinion, electric ignition was as great an advance over the tube as the tube was over the old slide.

He thought it very interesting to learn of the success of the tar separator, as the question of tar in the gas was a very serious matter. The arrangement described appeared to be very similar to what had been used by others for cleaning out the dirt from blast furnace gas. It was somewhat disapointing to him that the author had not given his views upon the vertical inverted cylinder type of gas engine. This was a design which was favoured by electrical engineering friends, and one that has many interesting details. Perhaps, in his reply, the author might be induced to give them the benefit of his experience in this particular direction.

Mr. JOSEPH BUTTERWORTH said that although the last speaker had commented on the paper at great length, neither he nor Mr. Atkinson had in any way hinted at any new departure from the old type of engine, as exemplified by the "Otto" cycle, patented by N. A. Otto in June, 1876. The paper described only improvements and certain details of the above type.

Now that so many kinds of cheap gas had been introduced, he had hoped that some entirely new type of engine would be introduced to use them to the best advantage. He would like to know which kind of cheap gas was considered the most economical for ordinary use.

As regards compounding (hitherto a failure), seeing that the pressure was obtained almost solely from the heat generated, more care ought to be taken to expand the gases quickly, *i.e.*, the low pressure piston ought to be some distance past the commencement of its stroke before the exhaust valve from the high pressure cylinder opens.

He was also of opinion that throttling the charge as against the old "hit and miss" governing caused a loss of economy in ordinary gas engines.

Mr. R. M. NEILSON thought that there was one point which had not been mentioned by the author when speaking of compounding, and which should not be ignored. In his opinion, the difficulties experienced in employing large gas engines were not due to the use of large cylinders, for cylinders as large had previously been used in steam engines. Neither were they due to the employment of high temperatures and pressures, for equally high temperatures and pressures had been previously employed in smaller gas engines. In his opinion, the difficulties were due to the *combination* of large cylinders with high temperatures and pressures. Now by compounding they could avoid this objectionable combination. They would confine the high

temperature and high pressure to a cylinder of moderate dimensions, while the large cylinder would be subjected to but a moderate temperature and pressure.

Mr. H. PILLING thought that the author had exhibited a great amount of reserve. He had expected when he saw the title announced in the syllabus, that Mr. Atkinson would have told them something about recent developments with large engines of say 1,000 HP.

He had recently seen seven 600 HP blowing engines under construction at Messrs. Richardson's, Westgarth & Co.'s works, with cylinders about 51ins. diameter, and with a 4ft. 6in. stroke. The weight would be about 160 tons each; he had also had the pleasure of seeing a similar gas engine at work, and noticed the extremely smooth and quiet running.

He could not see why there should not be some different jacket arrangement to enable the men to clean and remove deposit much more quickly, and suggested as a means to this end, that instead of adhering to the usual method of construction, with an inner heavy lever, heavy outer jacket, complexed jacketed combustion chamber, with all internal forces passed back into the combustion chamber metal, and then along the jacket to the main bedplate, it might be found safer and cheaper to construct the cylinder more like a steam engine cylinder with all its stresses self-contained. The jacketing to be effected by building up round the cylinder a light secondary independent shell, constructed so as to be easily removable without disturbing the valve gear and other similar details.

Mr. H. N. BICKERTON said that he agreed with some of the last speaker's remarks, especially with regard to the shortness of the paper, although he thought they must all be very pleased with it as far as the author had gone. The paper was in his

opinion mostly confined to the engines made at Openshaw, and they all knew very well that the author was well informed as to what was going on outside the Manchester district.

The principal developments in the gas engines since the early days were in the resurrection of the "Clark Cycle" engine, and the largest engine he ever had the pleasure of seeing was on the above system.

He thought the author should not depreciate the Continental gas engines because they would not run on town's gas, as possibly these were not intended for that purpose, and anyone who had one made knew fairly well what was required from these engines, and also knew how to meet the work they were intended for.

Regarding the exhaust valve shewn by the author, there were many good points about it, but the Clark cycle did not require any exhaust valve, which was an advantage.

With regard to compounding, the difficulty was no doubt due to the high temperatures as already mentioned by a previous speaker.

Mr. J. WATSON remarked that he would like the author to give them some information regarding the handling of large gas engines, and also whether it was possible to start one with the load on, which was required by some mills.

Mr. R. MATTHEWS observed that on referring to Diagrams 14 and 15, if instead of that drop they could have got a low pressure, he calculated that it would practically reduce the temperature something like 257 degrees, which would mean that the gases in the high pressure would have more time to burn, and thus they would be able to get more work out of it In addition to this the exhaust valves would not be so badly punished by the gases flowing from one end to the other.

He thought it would also be a great advantage if they could do with less jacket water, the loss being about 40%, whereas if they could reclaim some of it by using the waste heat in the jackets, there would not be a permanent waste.

Mr. A. SAXON said that if the particulars furnished in the paper were correct, they could perhaps make a liberal allowance on the claims of the gas engine makers.

He observed that a steam engine could drive cotton mills 56 or 58 hours per week for a year, and the cost would only amount to £1 per IHP per annum, and until the gas engine could compete against this he thought that steam engines would be made for some considerable time longer.

Mr. A. V. COSTER remarked that he had little to add to the discussion, except as regards the equilibrium exhaust valves of Messrs. Crossley's gas engines, which had received some adverse criticism at the hands of Mr. Bellamy. This type of valve, with developments had been applied to all Messrs. Crossley's gas engines from 80 BHP to 500 BHP and upwards. It was unfortunate that Mr. Atkinson had omitted from his paper Messrs. Crossley's vertical type equilibrium exhaust valve, with its head inside the compression chamber. It was incorrect to say that these valves were inaccessible, for either type of valve could be examined on the floor in from 10 to 15 minutes in all engines.

Their ease in opening, prevention of loss of power, and minimum wear and tear of gear, could be gauged from the fact that with a 10in. diameter equilibrium exhaust valve the load was only 440lbs., compared with 8,600lbs. load of a 10in. diameter unbalanced valve. The advantage of such a valve was well known to steam engineers, and it seemed a waste of time to argue against its use in gas engines. It was rather

interesting, in the face of Mr. Bellamy's criticism, to know that his firm had recently patented a spring opening gear for exhaust valves, which, although it prevented a sudden application of load on the worm gearing did not reduce the total load still to be lifted.

THE CHAIRMAN (Mr. E. G. Constantine) said that his feelings were somewhat relieved to hear that the steam engines were not to be done away with.

The paper as far as it went was an excellent one, and however they looked at the subject, the gas engine had come to stay, and would have to be reckoned with by steam engineers.

In his opinion, like most mechanical things, he thought that each engine had a special sphere of their own for which one engine would be better qualified to do the work than another.

He concluded by proposing a hearty vote of thanks to Mr. Atkinson for his excellent paper, which was unanimously carried.

Mr. ATKINSON said he was extremely obliged to the members for the courteous way they had received his paper.

Replying to Mr. Bellamy who spoke about the "scavenging" mentioned in the paper he had the honour to read before the Association in 1894, he said that there had been a great increase of pressure since that date, which was then only about 80 or 90lbs., whereas nowadays the pressure was about 110 and 120lbs., and this meant a very considerable reduction in the volume of the combustion chamber. There was also another thing, he was sorry to say, which did it more harm than anything else, and that was the increased noise of the exhaust. This was owing to some peculiar action of the long-pipe, which was not ascertained or realised at the time he read his paper in

1894. There had been instances where non-scavenging engines had been fixed to do heavier work than they were capable of doing, and the difficulty had been overcome by making these engines into scavenging engines. The cost of these engines with the long exhaust pipe were such that the intermediate purchaser very much objected to, and as they were often sold through agents, who were certain to look after themselves very carefully, they preferred to fix engines without the long exhaust pipes, which was also one reason why they had not been so largely adopted, as might have been the case.

As regards the exhaust valve casing being a separate piece, he said it was quite true that in most gas engines it was made in a separate piece and bolted on to the sides, but great trouble had been experienced with such engines owing to leakage, owing to there being a water joint as well as a pressure joint. If they would look at Figs. 5 and 6, they would find that the joint there had no water connection at all. He might say that a great number of small engines were made without a separate casting for the exhaust valve, but with a larger-sized engine it was not good practice to do this.

Mr. Bellamy had also referred to the inner metal being joined to the outer metal; he wished to say that they were at right angles, and that so far they had been working very satisfactorily, not having had a single one broken.

He noticed Mr. Bellamy also objected to the exhaust valve being put in a separate passage. It would no doubt seem better to put the valve in the opening chamber, but there were difficulties which arose from so doing, and therefore the firm with whom he was connected considered it best to put it as stated in the paper. The valve was thoroughly well supported at both ends, the unit pressure per square inch being an extremely small amount, and so far they have stood the test

very well. The exhaust valves as Mr. Coster had already stated were placed above the floor level, which was much better than having to lift it out of the pit. The compensating arrangement of the exhaust valve he looked upon as of most vital importance, and it was from bitter experience that caused his firm to arrange for some particular method of compensating. It was found that the compensating piston did not give any trouble. The small hole referred to by Mr. Bellamy was for the purpose of equalizing the pressure on the compensating piston.

As regards electric ignition, his firm had found in two or three instances that where purchasers had insisted upon electric ignition at the commencement, in a few months time they had asked for it to be converted into tube ignition. The double tube ignition he might add, had two independent tubes, and in the ordinary course both of them were at work, but if anything should go wrong with one of the tubes it could be shut off with a little screw without stopping the engine.

Referring to the question of the tar separator *versus* fans, spoken about by one or two of the members, he had no doubt that they had heard of the larger engines used on the Continent, with which some trouble had accrued through dust getting in, but this had been got over by employing fans, although these required to be driven at a very high velocity. When dealing with poor gases they would be dealing with large volumes which required a very large fan, and these took an enormous amount of power to drive them.

As regards the vertical gas engines he thought that to criticise these to a large extent would mean criticising competitors, and therefore it would be better to leave this subject alone. His firm were certainly making a few of these engines, but in his opinion the horizontal form was the best.

Mr. Butterworth had made some remarks on the fuel for gas producers, but in his opinion to go fully into this matter would

entail a great deal of time, although the subject was a very important one, and was quite deserving of an evening by itself. The question to a large extent was the quality of coal you would be able to use in these gas producers. The previous week he had seen one of Messrs. Crossley Bros.' gas producers where they had been burning common slack, costing 5/- delivered, and it was working very satisfactorily.

Referring to the compounding spoken about by Mr. Butterworth and Mr. Neilson, he said that this subject had been carefully studied by the late Mr. Frank Crossley, who had opened a direct connection from the high pressure cylinder to the low-pressure cylinder at two-thirds of the stroke of the piston of the high-pressure cylinder, but it did not meet with success. He had tried the jacket water from 60 degrees to 212, from which tests it showed there had been a slight gain in economy, but a loss in power which also had occurred in the compound engine.

Mr. Pilling had referred to the cleaning arrangements and to the Cockrill engine, but they must bear in mind that the makers of this latter engine had many advantages, through being such very large engineers, having their own mines, etc., that they could well afford to put down such engines. Regarding the cleaning arrangements he would only refer them to Fig. 2, from which they could see that a man could get at the inner portions to clean them. Respecting the quality of fuel mentioned by him, he had already replied to this question.

He noticed that Mr. Bickerton had complained about the shortness of the paper and that there was very little mentioned about other makes of gas engines, but he had thought it better not to go into other makers' engines, and only deal with matters with which he had daily experience.

With reference to compounding and more equally dividing the work in two cylinders, he thought there was a good deal in

this suggestion, but that would mean a departure from the "Otto" type of engine. He might mention that the late Mr. Frank Crossley had made some very interesting experiments on this point some years ago.

As regards handling larger gas engines and starting them with the load on, he said that quite recently his firm made an engine guaranteed to give 250 HP, and one condition was that it should start with 150HP on, which had turned out to be a success.

He was sorry he was unable to reply to Mr. Saxon who had astonished him very much when he stated that by steam they could get IHP. in a mill for £1 per annum, which however, he presumed only referred to the amount of fuel burned. He quite agreed with what Mr. Coster had said, which was correct, excepting that in the instance he referred to of the spring opening gear, the load on the gear wheels was distributed over a larger period and the pressure on the teeth was correspondingly reduced.

Mr. Savill wished to know if he had any information about double-acting gas engines. He had the pleasure of seeing some on the Continent, but he thought they were very much underloaded. He certainly was of opinion that it would be possible to make double-acting engines on the "Otto" cycle.

He agreed to a large extent with what Mr. Constantine had said in regard to these different engines having their own sphere of usefulness, and would therefore conclude his remarks by thanking them for the attention given.

The CHAIRMAN (Mr. E. G. Constantine) thanked the gentlemen for taking part in the interesting discussion, and the proceedings terminated.

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3 Plates follow illustrating this Paper.

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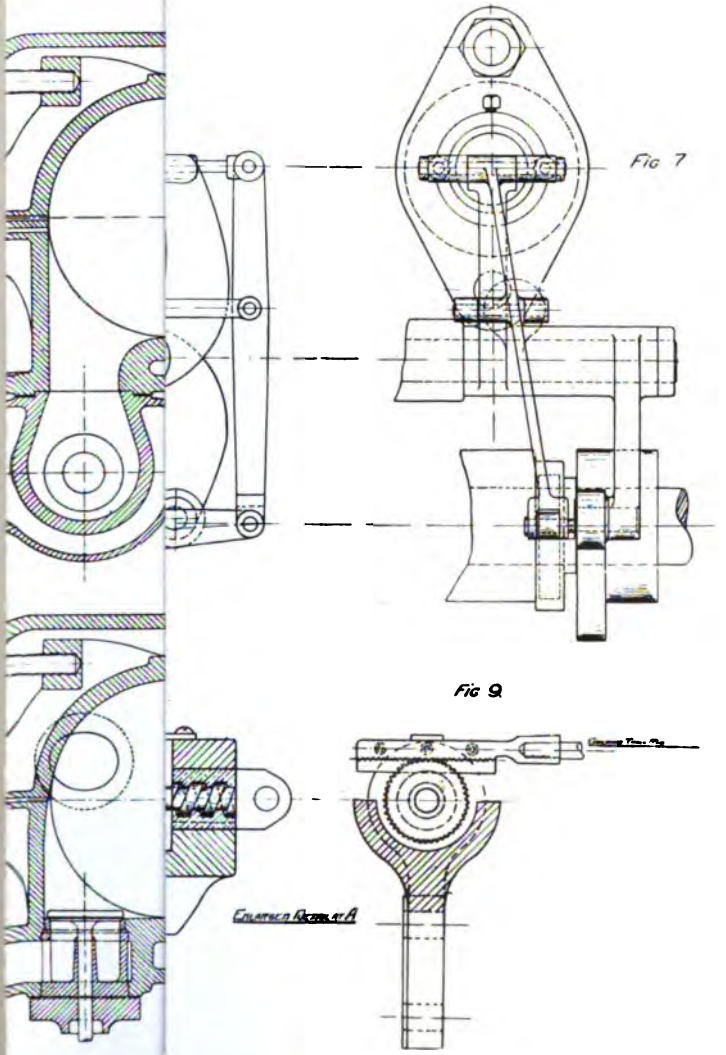

Fig 7

Fig 9

CH END. VERNOR CUT-OFF GEAR.

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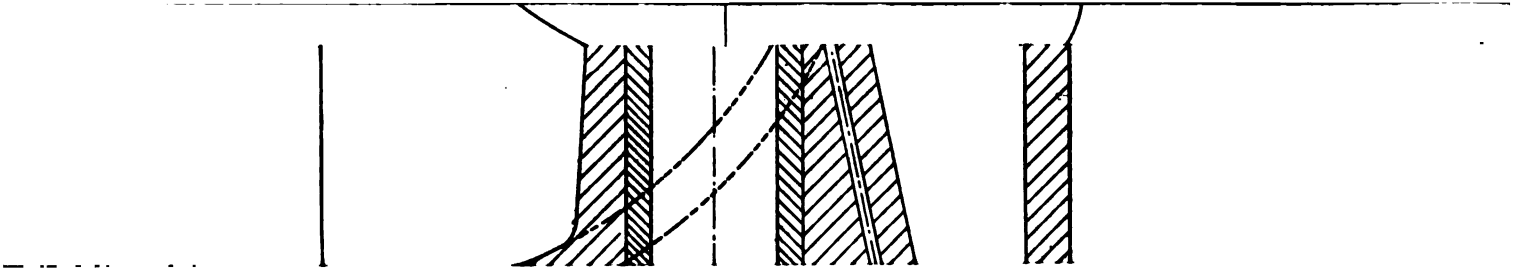

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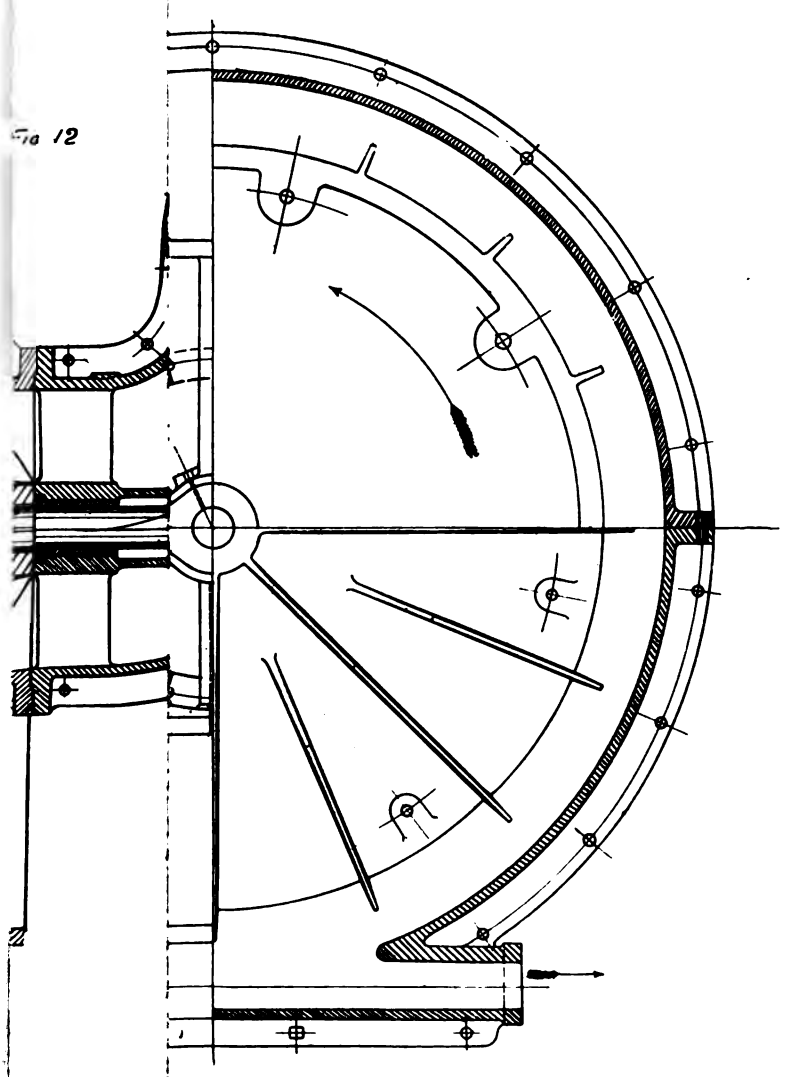
GAS

Fig 12



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PNEUMATIC TOOLS AND APPLIANCES.

READ SATURDAY, 14TH MARCH, 1903,

BY

Mr. EWART C. AMOS, M.I.Mech.E.,

LONDON.

In a paper on "Machine Tools" read by the author in 1899 before the Society of Engineers, at the Royal United Service Institution, London, he dealt briefly with the subject of pneumatic tools; the importance of these machines he there foreshadowed, although, at that time, comparatively little use had been made of them in this country, and in fact, as was stated by one of the speakers who took part in the disscussion, it was the first paper addressed to Mechanical Engineers in this country in which attention was called to pneumatic tools.

The author begs your kind indulgence in referring to this paper, and does so in order to show how comparatively short a time has elapsed since their recognition as a serious factor in the engineering world, although, it must not be forgotten, that several pneumatic tools of English invention had been in operation some 30 years before the present American designed machine. In the following year and in addition to a series of articles in the technical press, the author read a somewhat lengthy paper on the subject of Portable Pneumatic Tools before the Institution of Mechanical Engineers in London, in which he described the leading machines then on the market. As many of the members of this Association are probably familiar with that paper, it will be the author's endeavour as far as possible to avoid repetition, and to refer to only such machines as are novel, assuming that his audience is familiar with the well-known types, and with the general principles regulating the system.

It is the author's privilege to be in possession of the details of several new machines, particulars of which he places before this Association, but before doing so it may be interesting to refer to the subject of Pneumatic Tools in more general terms. Pneumatic tools, as generally understood, are essentially portable tools, and do not therefore directly enter into competition with fixed machines, excepting in this respect that it has now been found, in many instances, that it is far cheaper to do certain work in position rather than take it under a fixed machine, and to this extent competition exists, and even where the actual cost of the machining is greater with the pneumatic tool, the ultimate saving is greater still on account of labour saved in handling the work, and in other ways.

Dealing with the various types of Pneumatic Tools under separate headings, hammers and rivetters will be considered first. As you are probably all familiar with the "Boyer" hammers and rivetters which represent the standard type of this kind of tool at the present time, it is unnecessary to refer to their construction here, but attention is drawn to Plate I, Fig. 1, which is reproduced from a photograph of the latest type of deck rivetter. The simplicity of the device will be seen at a glance. It consists of a "Boyer" single-valve long-stroke hammer of the latest type, attached by means of a simple clip to the end of a weighted rod, which is itself attached to a small two-wheeled truck.

The objects are:—(1) To bring into use for the purpose of deck-rivetting a hammer of standard type, which can be also used for other forms of rivetting when detached from the jig.

(2) To assist the operator, since the balance weights shown add to the pressure exerted by his own weight; and he can again increase this by placing his foot on the bar or weights.

(3) To obviate the necessity of his laying the hammer down on the deck and picking it up again for each operation after

chipping off the rivet flush. This is provided for by suitable stops and lugs in the trolley, and also in the bar adjacent to the hammer.

One of the great desiderata in the use of Pneumatic Tools is to reduce multiplicity of types, and for this reason the above described arrangement helps to fulfil this object, since it converts an ordinary longstroke hammer into a deck-rivetter.

The valuable assistance obtained by the use of a pneumatic hammer for caulking and chipping are well-known to you, but as a reminder of the time saved by their use over hand labour, it may be mentioned that in certain cases the cost of caulking has been reduced from 2½d. to ½d. per yard, and at the same time the operator has been able to earn 30% more wages on the modified piece work rate.

Amongst a great bulk of reliable data now obtainable in respect to the saving effected by the use of Pneumatic Hammers, the following may be noted:—

(1) By the use of a "Boyer" long stroke hammer on combustion chamber work for marine boilers, the price of driving ⅞in. rivets in the seams has been reduced from 85/- per 100 rivets to 24/- per 100 rivets.

(2) A well-known boilermaker states that a No. 60 "Boyer" long stroke hammer is used for closing ⅞in. diameter rivets in the back ends of flues of Lancashire boilers, which are tested to 175lbs. per sqare inch, and the work is done by one man and a holder-up in two-thirds the time it takes two men and a holder-up by hand.

(3) The following is somewhat interesting.

COMPARISON OF HAND AND PNEUMATIC RIVETTING

Being controlled by the time limit allowed by the Boilermakers' Union.

How done.	No. of Rivets driven.	No. of Rivetters.	Holders-up.	Boys.	Time in hours.
Hand Rivetting	360	2	1	2	6
Pneumetic ,,	400	1	1	2	6

But even with this labour difficulty the saving in labour is not inconsiderable.

(4) A No. 1 "Boyer" chipping hammer when used for dressing the hardest kind of burr stones will reduce the cost of dressing from 7d. per square foot to 3d. per square foot.

(5) A No. 1 "Boyer" chipping hammer has proved very satisfactory when used for cutting doorways in a solid brick wall 2ft. thick. The method employed was to cut a border line, or in other words one layer of brick out of the wall on each side of the doorway, and then cut one layer about every ten rows, after which it was possible to pry down the large pieces, and by this means one man was able to cut out two of these doorways in a day.

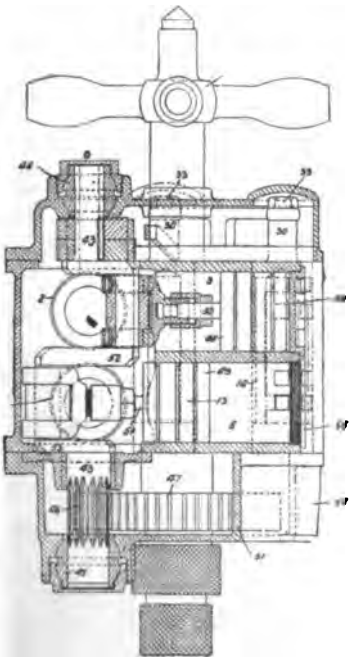
DRILLING MACHINES.

The "Little Giant," the "Boyer," and "Whitelaw" drills have now been sufficiently long upon the market to be familiar to most of you, and therefore it is unnecessary to describe them, but the drill which the author is now able to bring to your notice is entirely new. The machine itself, however, has already undergone exhaustive trials, and will shortly be placed on the market. It may be said, at the outset, that it forms a very valuable improvement on the well-known "Little Giant" drill, whereby the use of the motive fluid or compressed air is economised, and the machine is at the same time made reversible without interfering with the screw feed. As you probably know the "Little Giant" drill has been made in two forms, reversible and non-reversible. In the latter case a screw feed was used, whilst in the former a throttle-handle placed on the top of the machine made it very suitable for such operations, as tube expanding, tapping, reaming, wood-boring, etc. A demand however was then made for a screw-feed machine of this type which should also be reversible. The original machine was therefore modified to comply with these requirements, and

a number of them are now in use. Whilst securing the desired object, they do not however possess the advantages of this machine either in economy of working, or in methods of construction. As it may be of interest to members of this Association to have a detailed description of this machine, such is given in the form of an Appendix, but the main features may perhaps be summed up in a few words.

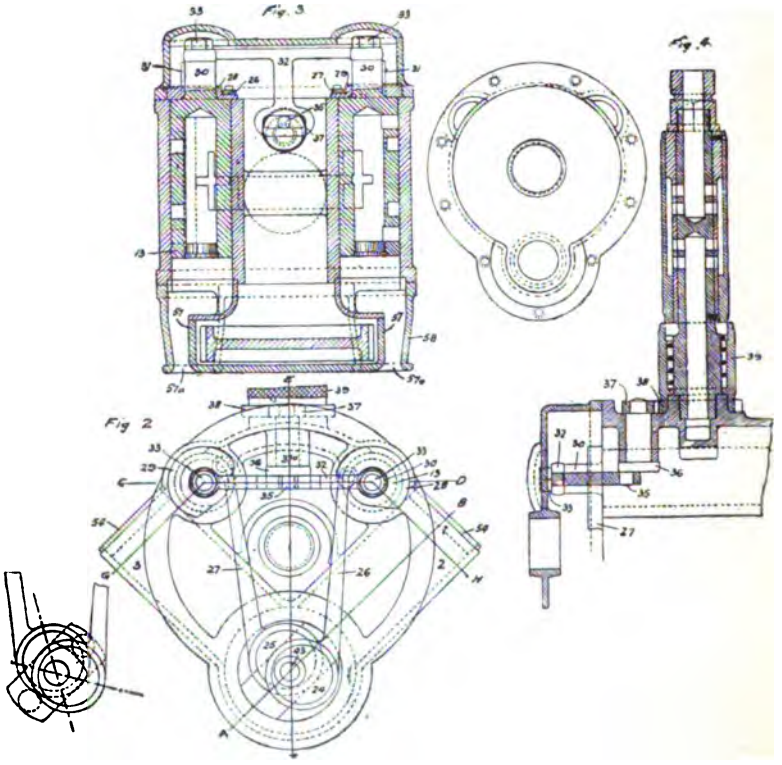
In appearance, as will be seen by reference to Plate I. Fig. 2, which is taken from a photograph of the machine, it resembles closely the "Little Giant" drill externally, and reference to the appendix will shew that this resemblance also occurs in respect to the air cylinders and pistons, both as regards their type and their positions relatively to one another, and to the crank shaft. The divergence however, is in respect to the valves which are

Fig. 1



of the oscillating or Corliss type, and take the place of the reciprocating piston valves used in the "Little Giant" piston air motors.

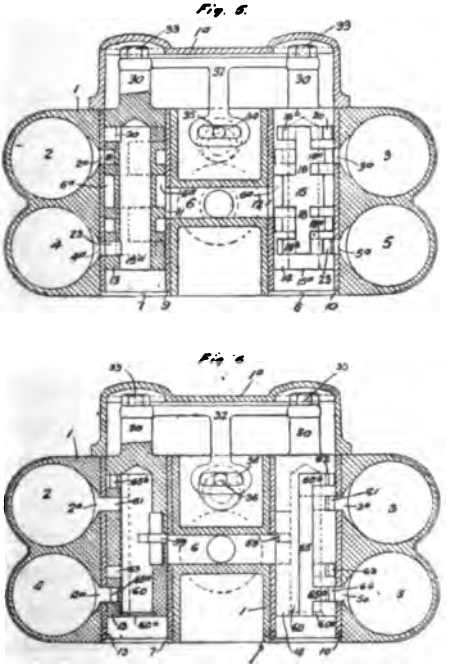
Referring briefly to the illustrations, Fig. 1 is a sectional elevation of the machine taken on the line **A-B** of Fig. 2. Fig. 2 is a rear end or top view of the machine with cover removed, shewing the eccentrics on the crank-shaft, and their connections to the controlling valves. Fig. 3 is a vertical sectional elevation of the machine body taken on line **C-D** of Fig. 2. Fig. 2 is a rear end or top view, etc. Fig. 4 is part of a sectional elevation on line **E-F** of Fig. 2. Fig. 5 is a diagrammatic view taken on line **G-H** of Fig. 2.

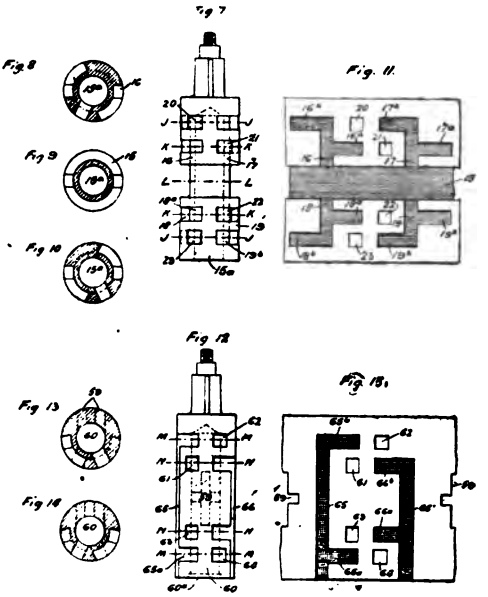


Special attention is here drawn to the fact that the drawings show two types of valves, the one in which the air pressure is admitted to the working cylinders through the interior of the valve and exhausted from the cylinders by passages in the exterior of the valve, as in Figs. 1, 2, 3, etc., whilst the other valve admits air pressure through passages in the exterior of the valves, and exhausts through the interior of the valve as in Fig. 5, and it is this latter system that is being adopted in actual practice, although both will serve the desired purpose.

Unless this fact is borne in mind some confusion may arise in following the description.

To those who may not be entirely familiar with the construction of a "Little Giant" drill, it may be useful to remind them that in this type of drill, the motor consists of 4 single





acting cylinders arranged in pairs, and having each pair of pistons connected to opposite ends of a double crank-shaft. The pistons of each pair travel in opposite directions at all parts of the stroke to effect smooth running. This arrangement also exists in the drill under consideration. Now, without going to the extent of following the passage of the compressed air through the various ports as is done in the Appendix, it will be sufficient to say that the oscillating of the two Corliss valves by suitable eccentrics on the crank-shaft automatically admits live air to each of the 4 cylinders in turn, each valve controlling the inlet and exhaust of air pressure to and from two cylinders forming a pair.

The reversal of the machine is effected by turning the sleeve 39, and this by means of a gear wheel 38 actuates the yoke 32, which latter being connected to the stems 30, of the valves 13 and 14, forces the said valves forward in their bushings, and

as a result of the altered position of the ports in the valves and bushings in relation to the pistons in the cylinders, reverses the direction of the crank-shaft, and thus the drill or bit in the machine.

A special feature of this reversing arrangement is that owing to its proximity to the throttle handle, which is held by the operator, it enables instant reversal to be made without leaving go of the machine, at the same time its position at the side of the machine enables a screw-feed to be used.

The efficiency of a Corliss type of valve is well known, but in addition to this, the position of the valves close to the cylinders gives the least amount of clearance and saves a great deal of air which had formerly to be driven out of the ports at each stroke and which also reduced the effective pressure of the live air.

It will be noted that the crank-shaft bearings are spherical, thus securing true alignment. The spindle is also fitted with a gland which prevents leakage of oil and ingress of dirt.

The machine generally is well designed for rough work and should prove highly efficient.

The advantages of pneumatic rotary motors for purposes other than drilling are now well recognised as for instance, in heavy tube expanding, boring, cutting out manholes, etc., but certain of these applications call for slower speeds than are required for ordinary drilling; to meet these conditions various speed reducing gears have been devised and form valuable attachments. Right-angle attachments for use with pneumatic motors also form necessary adjuncts, and the absence of these causes the machine to lose much of its usefulness. In fact it must now be admitted that attachments and jigs for use in combination with pneumatic tools, not infrequently are as valuable as the tools themselves, and in this direction there would seem to be plenty of room for new inventions.

The following data as to saving effected by the use of pneumatic motors may prove interesting:—

(1) By the use of a pneumatic drill special boring bar for boring the stern post for stern tubes in large vessels, one man is doing the same work in 5 days that previously took 7 men 7 days to do by hand.

(2) In a comparison made at the works of an English Railway Company, between ratchet drilling and pneumatic drills when drilling holes $\frac{1}{16}$in. diameter in $\frac{9}{16}$in. copper, the result shewed that the ratchet required 8½min. as against 45secs. with the pneumatic drill, and the operator exercised very much less effort which is an important factor.

(3) In a 10,000 hole run the saving effected by the use of pneumatic motors over hand drilling is shewn by a reduction from 1s. 8d. per dozen to 8d. per dozen when drilling $\frac{1}{16}$in. dia. holes in ½in. plate and in addition the operator earned 30% more wage.

When making this comparison the time taken for shifting the machine and jigs, removing twist drills for re-grinding, etc., was all taken into account.

(4) During some extensive tests made by the author on two Battleships at H.M. Dockyard, Portsmouth, the following amongst other results were obtained, and these it must be noted were when the tools were used by unskilled operators.

Drilling $1\frac{1}{8}$in. dia. holes in 2 inch steel plates.

By hand drilling 12 holes in 1 day.

By pneumatic drilling 11 holes in 2 *hours*.

$1\frac{9}{16}$in. dia. Ventilating holes in 2 inch mild steel.

By hand drilling 1 hour per hole.

By pneumatic drilling 10 minutes per hole.

$\frac{3}{4}$in. holes in $\frac{3}{8}$in. steel angle iron.

By hand drilling 12 holes per hour.

By pneumatic motors 40 holes per hour.

DESCRIPTION OF THE HANNA PNEUMATIC SCREEN SHAKER.

The advantages of compressed air as a motive force have, of course, been recognised for a long time, but the introduction of pneumatic tools has undoubtedly given its adoption a great impetus. In many shops it is frequently found that having installed an air compressing plant other uses can be found for this form of energy beyond driving what are generally known as pneumatic tools. Without enumerating these, many of which will be familiar to you, the author desires to draw your attention to a novel form of screen shaker which has recently been placed on the market and which is meeting with great success.

It is the common practice in most foundries in this country to screen moulding sand by hand labour, a somewhat costly process when compared with what can be done with the machine which is about to be described.

The object for which this machine has been designed is to provide a simple, economical and efficient machine for screening sand, and reference to the accompanying drawing will at once indicate its simplicity.

It may first be mentioned that the air pressure necessary to operate this machine most economically is about 80lbs. per square inch, which is the usual pressure adopted for driving portable pneumatic tools, and the quantity required is 12 cubic feet of free air per minute.

The machine is at present made in three designs. (1) As a tripod machine. (2) As a high frame machine for attachment to a wall, girder or similar support. (3) As a low frame machine for a similar method of attachment.

Referring first to Fig. 16, **A** is the tripod, **B** is the screen holder into which an ordinary screen or riddle may be fixed.

This screen holder is supported directly upon two arms **C-C**, which are pivoted at the points **D-D**. In order to vibrate the screen holder a cylinder **E** attached to the tripod is provided

with a reciprocating piston and piston rod, the latter being suitably connected to the screen holder so that the reciprocation of the said piston causes the screen holder to receive the necessary shaking motion.

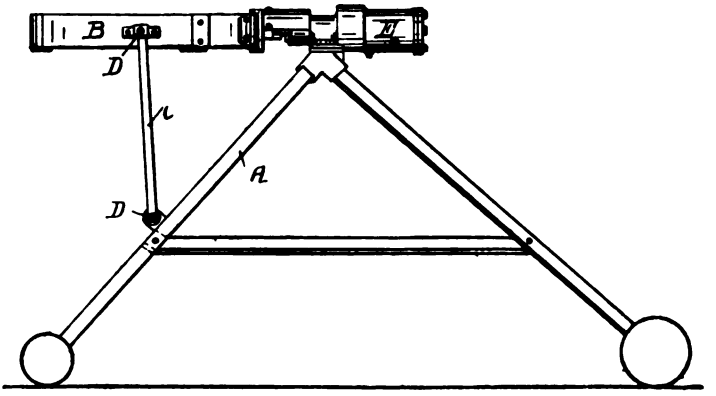


Fig. 16.—Elevation of "Hanna" Screen Shaker.—Tripod Form.

In order to more fully understand the action of the compressed air upon the moving piston reference must be had to the detached drawing, Fig. 17, which shews the section of the cylinder and piston with the necessary parts. In this Fig. E is the cylinder and F the piston which is formed in one piece with the piston rod G. H is the inlet leading from the main air supply.

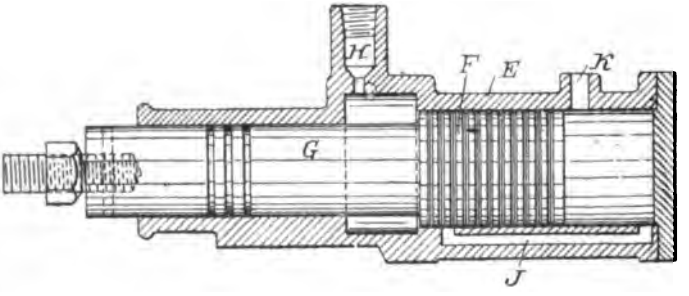


Fig. 17.—Section shewing Piston and Cylinder with Ports of "Hanna" Screen Shaker.

J is a port leading to the back of the piston and K the exhaust. The action of the compressed air in causing a reciprocation of the piston is as follows :—

In the drawing the piston is shewn towards the front end of the cylinder, and on the admission of air at H will force the piston and screener backwards. When the piston has travelled sufficiently back to uncover the port J, air will travel to the back of the piston and will counteract the backward motion of the piston and drive it with the screen holder forwards, the exhaust taking place through the port K. By this arrangement it will be seen that the compressed air is caused to act constantly against the front end of the piston and intermittently on a superior area against the rear end of the piston, and in that way an automatic and constant reciprocation of the piston is obtained without the use of any valve.

Amongst the advantages offered by such a device are the simplicity and portability of the arrangement. The holder carries an 18 inch diameter screen, and screens can be changed in the fraction of a minute. When using a ½in. mesh riddle the machine will shake all the sand that two men will care to shovel; and in actual practice in every day work in a foundry it has been shewn that a labourer is able to riddle as much sand in 2½ minutes as a moulder and a labourer can do in half an hour. As will be noted by a reference to the photographs it is essentially portable, the tripod machine weighing only 100lbs., whilst the post machine weighs only 50 lbs.

As already stated the machine requires 12 cubic feet of free air per minute, or say 720 feet per hour, which will cost 2½d. per hour, and add to this 1¼d. per hour for depreciation and repairs, plus 7½d. per hour for labour, we have as a total 2½d. + 1¼d. + 7½d. = 11d. per hour, and the machine will have riddled as much sand in one hour as a man would do in five

hours. The cost of his wages alone during this time would be 8/-, so that the saving effected shows at least 2/1.

The post machine can of course be used equally well as a fixed machine, and in this case steam instead of compressed air may be used to drive it when compressed air is not available.

Such a machine is a great labour saver and a good money maker, and being somewhat new to this country the author ventures to hope that the description and illustrations may prove interesting. Various types of the machine are shewn on Plate II.

The author desires to draw your attention to another development in the use of compressed air, and that is a portable rock drill as shewn in elevation in Plate I. Fig. 8, and in section in Fig. 18. Without entering into a full description of this machine, for which time will not permit, it is only necessary to say that it has been designed to take the place of the ordinary rock drill for certain classes of work, and owing to its lightness and extreme portability (since it requires no mounting whatever) it has proved itself to be highly efficient and to have achieved this object.

Referring to the sectional views, it may be stated that compressed air causes the moving piston to reciprocate at a high speed as in an ordinary pneumatic chipping hammer, and this in turn strikes the end of the bit giving the desired percussive action to it. The drill bit is enveloped in a tube and by means of a blast of air running through it, clears the hole of all obstruction. This arrangement is extremely valuable in cases where the class of rock being bored does not require the use of water.

For drilling "block-holes" in quarry work for "plug and feather" work as carried out in cutting stone to desired dimensions (by drilling a number of small holes in line previous to splitting) and in many other classes of work, the saving effected in both time and labour over the old method of feeding

the drill by means of a screw and adjusting the tripod in position is shewn to be very considerable.

The mechanism is so simple and free from complication, and the machine is so easy to handle, that unskilled labour can be

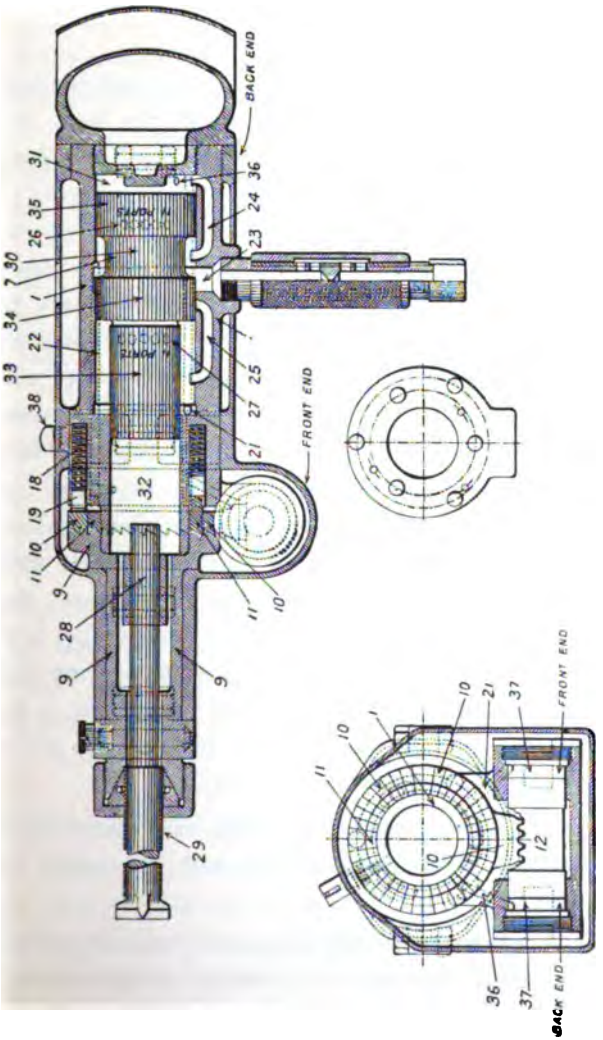


Fig. 18.—Sectional views of Chicago Portable Rock Drill.

employed to use it. The machine complete, weighs only 50lbs., requires 42 cubic feet of free air per minute, and will do the same work in $\frac{1}{20}$th the time taken by hand. As an example of actual work done, a lad of 18 years has drilled 120 holes $\frac{1}{2}$in. diameter × 9in. deep in granite in 6 hours.

PORTABLE PLANTS.

In certain cases it is desirable that not only shall the tools be portable in the ordinary sense, *i.e.*, within the limit of the flexible air mains, but also that the whole plant, including the air compressor receivers, etc., shall be capable of being easily moved about. This is particularly the case in railway bridge repairs and similar classes of work. Such a plant is shewn on Plate I. Fig. 4., this particular one was supplied to the Great Southern and Western Railway of Ireland. Many such plants are now in use and are doing splendid work. It will be noted that the whole of the machinery is contained in the permanent way covered wagon, and this can be put in immediate operation wherever it may be placed as it is entirely self-contained and portable. The plant consists of (1) 12HP. horizontal type boiler with necessary fittings, injector, etc. (2) a steam-driven air compressor having a capacity of 134 cubic feet of free air per minute. (3) a water tank and pipes for supply of water used for cooling the air cylinder the tank also serving as a feed-water tank to boiler. (4) air receiver. (5) flexible hose and connections. (6) small bench and vice. (7) eight pneumatic tools.

Such a plant costs approximately £670 exclusive of the truck and is capable of operating six to eight pneumatic tools simultaneously.

Wherever greater portability is required, *i.e.*, independence of the railway track, and when it is desired to take it along the roadway, the same arrangement is used but the truck is made

lighter and ordinary road wheels provided. Semi-portability may be obtained by simply bolting the compressor down to timber or girder foundations, as is frequently done by gas-holder manufacturers and other contractors who may require the plant at work in one particular place for a few weeks, more or less.

Again, where neither steam-power or electric-current are available, the compressor may be conveniently driven by an oil engine. In this case, it is a good practice to place the oil and air cylinder together on the same crank-shaft, the whole being mounted together with the air receiver on a road truck.

AUTHOR'S VISIT TO UNITED STATES.

Last year it was the author's privilege to visit the United States, and a day was spent at the shipbuilding yards of Messrs. William Cramp & Sons, on the Delaware river, Philadelphia, with the object of investigating the progress made in the use of pneumatic tools on this class of work.

There are in use in this yard some 700 to 800 pneumatic tools of various description, a large number of which are devoted to rivetting of all kinds, including flush rivetting.

Messrs. Cramps' experience in the use of pneumatic tools is entirely favourable to their universal adoption for flush rivetting of all kinds, both on the ground of economy and also because the holes are better filled than with hand driven rivets. In addition to this it is far less laborious for the operator.

If anyone doubts the statement about the rivet filling the hole let him compare the difference between breaking up a pneumatic rivetted boiler or ship and a hand rivetted one, in the former case drilling out the rivets is generally the quicker way. Some actual figures given to the author at Messrs. Cramps' may be interesting to the members of this Association. These were

obtained from actual every day work, and were based on the driving of several thousand rivets. For instance, 1in. diameter steel countersunk rivets costing 4 dollars per hundred by hand riveting, cost 3½ dollars when driven by pneumatic riveter. Perhaps 2/- per 100 may not appear a great saving, but it must be borne in mind that there are a good many hundred rivets in a ship, and what is more important, the work done was far superior, in addition to which the operators earn more and are better satisfied and less fatigued. Another figure may be given, ¾in. rivets in water tight work costing 2·75 dollars per 100 by hand riveting were done by the machine for 1·25 dollars. which must be admitted is a very great saving.

It may be interesting to state that in a large installation such as that in Messrs. Cramps' yard, the cost of air supply may be taken at about 8 to 10 cents per day per tool.

As to the time taken, a gang will close about 250-1in. dia. flush rivets in the hull of a ship per day.

In respect to economy which Messrs. Cramps have secured, it must be noted that it is the extensive application of jigs and appliances in connection with pneumatic tools that has made pneumatic riveting so popular, and these appliances can now be readily obtained in this country when desired.

In addition to the riveter and drill the pneumatic chipping hammer finds much work in Messrs. Cramps yard for cutting out manholes, etc., in addition to ordinary chipping, and generally the pneumatic tool is brought into action wherever possible.

In conclusion the author claims your kind indulgence in respect to what may appear a somewhat disjointed paper and claims your kind consideration of this deficiency on the ground that he has attempted to bring to your notice a few special machines and features of the system rather than a connected record of the whole industry.

Pneumatic tools have now passed the stage of experiment and, moreover, the standard machines are more or less familiar to those in the engineering profession so that specialization becomes the order in this as in most branches of machinery.

Regarding the various data given in respect of the work done by pneumatic tools it might appear at first sight that the various results enumerated somewhat conflict with one another, but it must be remembered (1) That they are the result of actual practice and to that extent are interesting. (2) That outside conditions, not perhaps notified when giving the results referred to, have produced a variation in time and cost on what would appear to be quite similar jobs. (3) That ¾in. rivets or any other size that may be named take a longer or shorter time to close according to their position and shape of head, and the same remark applies also to every class of work whether drillling, riveting, or chipping, etc. In other words, that local conditions have to be taken into account when making a comparison, and finally it is especially necessary to take into account the human factor which plays a very considerable part even when handling pneumatic tools.

The author will be pleased to answer questions, and trusts that his paper generally may produce a good discussion.

APPENDIX.

DESCRIPTION OF "HAYES" PISTON AIR DRILL.

This drill consists of an engine of the piston type with fixed cylinders and cylindrical controlling valves arranged at right angles to the cylinders. The pistons of the cylinders are connected as usual to the crank-shaft (which latter works the drill spindle or tool socket by means of the usual toothed gearing), and the controlling valves are actuated by eccentrics

on the crank-shaft, being oscillated by the eccentrics during the revolutions of the same so as to control the admission and exhaust of the compressed air to and from the working cylinders. The controlling valves are connected by means of a yoke to a reversing sleeve on the handle of the machine, and are thus capable of being directly actuated to reverse the direction of rotation of the crank-shaft. These valves have a double set of ports adapted to co-operate with the air inlet or the exhaust ports or passages.

Special attention is here drawn to the fact that the drawings shew two types of valves: the one in which the air pressure is admitted to the working cylinders through the interior of the valve and exhausted from the cylinder by passages in the exterior of the valve as in Figs. 1, 2, 3, etc., whilst the other valve admits air pressure through passages in the exterior of the valves and exhausts through the interior of the valve as in Fig. 5, and it is this latter system that is being adopted in actual practice although both will serve the desired purpose. Unless this fact is borne in mind some confusion may arise in following the description.

In order that the machine may be readily understood, reference must be made to the accompanying plates in which:—

Fig. 1 is a sectional elevation of the complete machine taken on the line **A-B** of Fig. 2 through the two right-hand cylinders.

Fig. 2 is a rear-end or top view of the machine with cover removed, showing the eccentrics on the crank-shaft and their connections to the controlling valves.

Fig. 3 is a vertical sectional elevation of the machine body taken on line **C-D** of Fig. 2.

Fig. 4 is part of a sectional elevation on line **E-F** of Fig. 2.

Fig. 5 is a diagrammatic view taken on line **G-H** of Fig. 2.

Fig. 6 is a diagrammatic view also taken on line **G-H**, Fig. 2, but shewing the alternative form of controlling valve.

Fig. 7 is an elevation of one of the controlling and reversing valves shewn in Fig. 5.

Figs. 8 and 9 are sectional plan views taken on lines J-J, J-J and L-L of Fig. 7.

Fig. 10 is a sectional plan on lines K-K, K-K of Fig. 7.

Fig. 11 is a diagrammatic outlay of the combined controlling and reversing valves shewn in Figs. 5 and 7.

Fig. 12 is an elevation of the alternative form of controlling and reversing valves shewn in Figs. 3 and 6.

Fig. 13 is a sectional plan view on lines M-M, M-M of Fig. 12.

Fig. 14 is a sectional plan on lines N-N, N-N of Fig. 12.

Fig. 15 is a diagrammatic outlay of the combined controlling and reversing valves shewn in Figs. 3, 6 and 12.

Fig. 16 is a plan view of the gear case shewn in Fig. 3 showing the final exhaust outlets hereinafter referred to.

The same numbers indicate the same or corresponding parts in the several figures of the drawings.

1 is the main casing or body of the machine comprising the air cylinders 2, 3, 4, 5, the air chamber or passage 6, and the controlling valve chambers 7 and 8, all formed in one casting. 1A is an end cap or cover attached to the main body 1. The valve chambers 7 and 8 are arranged at right angles to the cylinders 2, 4, and 3, 5 respectively, as clearly shewn in Figs. 2, 3, 5 and 6. 9 and 10 are ported valve bushings respectively in the valve chambers 7 and 8. 11 and 12 are ports respectively in the bushes 9 and 10. 2a, 4a, and 3a, 5a are pairs of ports also respectively in the bushes 9 and 10, the former connecting with the corresponding ports of the respective cylinders 2 and 4, and the latter connecting with the corresponding ports of the respective cylinders 3 and 5. 13 and 14 are the controlling valves fitted to work respectively in the bushes 9 and 10; each of the valves 13 and 14 is provided with a double set of inlet and exhaust passages or ports for controlling the inlet and exhaust of

compressed air to and from each cylinder to which said valve applies, one set of said inlet and exhaust passages or ports being employed for admitting compressed air to and exhausting it from the working cylinder for driving the drill spindle or tool socket in the normal or right hand direction, the other set of said ports being employed when working in the reverse direction as hereinafter described.

The form of valve generally used is shewn in detail in Figs. 5, 7, 8, 9, 10 and 11, in which pressure is admitted to the working cylinders through channels or passages in the outside of the valve, and the exhaust takes place through ports leading to a central passage in the valve. In Fig. 5 the valves 13 and 14 and the bushes 9 and 10 are identical in every respect, so that a description of one valve serves for both. In these figures 5, 7, 8, 9, 10 and 11, 15 is a reduced diameter or neck formed in the valve, the space between the said neck and the valve bushing forming a pressure chamber 6a (in Fig. 5), to which compressed air is constantly admitted from chamber 6, in the machine body through the port in the valve bushing when the throttle valve controlling the inlet of air from the source of supply is held open. Looking at the right hand valve 14 in Fig. 5, and at Figs. 7 and 11 inclusive, 16 is a channel or passage formed in the face of the valve on one side, and 17 is a similar channel or passage formed in the face of the valve on the other side opposite to 16, the general form of these channels or passages is shewn in the view of the right hand valve 14 in Fig 8, and also in the outlay of the valve shewn in Fig. 11, said passages 16 and 17 being provided respectively with branches 16a, 16b, and 17a, 17b. Both these passages, 16 and 17, with their branches as above set forth are inlet passages for conducting the air to the working cylinder (in this case the upper right hand cylinder 3 in Fig. 5), the passage 16, for example, being the inlet passage when the crank shaft is being rotated so as to drive the tool or tool socket in the normal or

right hand direction, the passage 17 being the inlet passage when working in the reverse direction.

There being four fixed cylinders in this type of motor (said cylinders being arranged in pairs in the casing 1, the pairs of cylinders being at right-angles to each other and to the crank-shaft) each controlling valve (13 and 14, Fig. 5) is arranged to control the inlet and exhaust of air to and from two cylinders forming a pair, for example, in Fig. 5 the valve 14 controls inlet and exhaust of pressure to and from the cylinders 3 and 5 both for normal and reverse working, the pressure inlet passages marked 18, 19, provided opposite to each other in the face of the valve and having (see Figs. 7 and 11) branches 18a, 18b and 19a, 19b respectively, being the inlet passages for the cylinder 5. 20 and 21 (see Figs. 7 and 11) are the exhaust ports in the valve, leading to the central exhaust passage 15a therein for the exhaust of air from cylinder 3, and 22 and 23 are the exhaust ports in the valve, also connecting with passage 15a, for the exhaust of air from cylinder 5, the ports 21 and 22 for example, being respectively the exhaust ports for the cylinders 3 and 5 when the pistons of these cylinders are operating the crank-shaft to drive the tool or tool-socket in the normal or right-hand direction, ports 20 and 23 acting to exhaust the cylinders 3 and 5 respectively, when the crank-shaft is working in the reverse direction.

Referring to Figs. 1, 2 and 3, the controlling valves 13 and 14 are oscillated in their bushings, so as to control the inlet and exhaust of air to and from the working cylinders, by means of eccentrics 24, 25, on the crank-shaft, the rings on these eccentrics being connected, respectively, by rods 26, 27 to collars 28, 29 on the valves 13 and 14; these collars are slidably mounted each on a stem marked 30 (see Figs. 3, 5, 6, 7 and 8) on each of the respective valves, said collars being held against rotation with reference to the valve and stem by means of a feather 31 on the

stem engaging a groove in the collar. Connected to the stems 30 of both valves is a T-shaped yoke 32, reduced diameters on the stems 30 bearing freely in the ends of the cross-bar of the yoke which is retained on the stems 30, by means of nuts 33 (see Figs. 1, 2, 3, 5 and 6) screwed on the threaded ends of the stems.

A slot 34 is provided in the vertical arm of the yoke 32, with which a pin 35 on a disc (or crank) 36 engages, said disc being connected to a pinion 37 (see Figs. 2 and 4) with which a toothed-wheel 38, on a sleeve 39 gears. The sleeve 39 is rotatably mounted on the usual hollow handle 40 (see Fig. 4) of the machine through which the air pressure from the source of supply is admitted to the air chamber 6, in the machine body. 41 indicates an ordinary throttle valve, adapted to be actuated by means of a sleeve 42, on handle 40, for opening and closing the air supply.

Referring now to Figs. 1 and 2, 43 is the crank-shaft, whose ends bear in end bearings 44, 45; 46 is the pinion on the crank-shaft, which pinion gears with gear-wheel 47 on the tool-socket so as to revolve the latter. 48, 49 are the pistons in cylinders 3 and 5 respectively, and 50, 51 the piston rods connecting pistons 48, 49, respectively to the cranks 52, 53 on the crank-shaft, the similar piston-rods and pistons of the cylinders 2 and 4 being also connected to said cranks.

54, 55 are screwed-in cylinder caps, and 56 (Fig. 1) is the usual feed-screw head.

At the tool-socket or gearing end of the machine body or casing 1, is a chamber or gear case 57 (see Figs. 1 and 3); 58 is a ring or annular section cast in one with the gear case and screwed on or otherwise attached to the machine body 1, the ports or channels marked 57a formed between ring 58 and the gear case 57 being the final exhaust outlets to the atmosphere which register with the controlling valve chambers. 58a is a cover part or neck detachably connected to the machine body 1,

and to the gear case 57, wire-gauze 58b being inserted between the valve chambers and the final exhaust ports 57a.

Figs. 1, 3, 6, 12, 13, 14 and 15 shew the alternative form of the combined controlling and reversing valves. The two valves 13 and 14 shewn in Figs. 1, 3 and 6, are identical in every respect, so that it is only necessary to describe one of the said valves. With this form of valve the air pressure is admitted to the working cylinders through the interior of the valve, and is exhausted from said cylinders by way of channels or passages on the exterior of the valve, instead of being admitted through passages on the exterior of the valve, and exhausted through the interior of the valve as described with reference to Figs. 5, 7, 8, 9, 10 and 11.

Referring to Figs. 6, 12 and 15, 59 is the inlet port connecting with a central chamber or passage 60 in the valve, and also registering with the air pressure chamber or passage 6 in the machine body 1. A plug or cap 60a closes the lower end of chamber 60. 61, 62 are inlet ports leading from the central chamber 60, and adapted to register with the inlet ports 3a leading into cylinder 3, port 61, for example, acting for the inlet of air pressure to the cylinder when the motor is driving the tool in the normal or right-hand direction, and port 62 acting for inlet when the motor is working the tool in the reverse direction.

63, 64 are inlet ports leading from the central chamber 60, and adapted to register with the inlet port 5a to the cylinder 5 (see Fig. 6), port 64, for example, being employed for the inlet of air pressure to said cylinder when the machine is working in the normal or right-hand direction, and port 63 acting for inlet when working in the reverse direction. 65 and 66 are the exhaust channels or passages on the face of the valve, the passages 66 and 65 acting, for example, respectively for exhaust of pressure from both cylinders 3 and 5, when the motor is running in the normal direction, and vice-versa; passages 65 and 66 acting for exhaust

respectively from cylinders 3 and 5, when working in the reverse direction. The general form of these exhaust passages is shewn in Fig. 15, said passages 65 and 66 having branches 65a, 65b, 66a and 66b respectively.

The working may be briefly described as follows:—

Assuming the motor to be operating the tool in the left hand direction, and referring first to Fig. 5 which shows the form of valve for taking the air pressure on the outside and exhausting through the centre of the valve; the right hand valve 14 is in the position to which it has been oscillated by the eccentric 25 on the crank shaft, in which its passage 16 is just about to admit air pressure to the cylinder 3, said pressure being admitted (by opening throttle valve 41 Fig. 4) to the chamber or passage 6 in the machine body 1, thence through port 12 in the valve bushing 10 into the space in the valve chamber between said bushing and the neck 15 on the valve, and thence by way of channel or passage 16 and its branch 16a to the port 3a leading into cylinder 3, the pressure also passing up channel 16 into its branch 16b, which latter in this case acts as a pressure balancing area; at the same time the air pressure in cylinder 5 has just commenced to exhaust through the port 23 leading into the central passage 15a of valve 14, whence it passes to the atmosphere through the open end of said valve and out through the open space 57a (see Fig. 3) in the gear case end of the machine body. Also at the same time the left hand valve 13 has been oscillated so that its inlet passage 16 is fully open to the port 2a (or in other words, port 2a is fully uncovered or opened to passage 16) leading into cylinder 2, so that the piston in this cylinder has received its full air pressure (and the valve 13 is about to be moved or oscillated to the position for permitting exhaust of air from the cylinder through the exhaust port 21 (see Figs. 7 and 11) and central passage 15a in valve 13, and thence out through space 57a (Fig. 3) to the atmosphere) and cylinder 4 is now fully

open to exhaust through exhaust port 23 and central passage 15a of valve 13, and thence through final exhaust outlet 57a. Now as the crank shaft is revolved the valves 13 and 14 will continue to be oscillated (through the connecting rods 26, 27 to the eccentrics 24, 25) so that inlet passage 16, 16a of right hand valve 14 will be fully opened to cylinder 3 through port 3a, and exhaust port 23 of said valve will be fully opened to cylinder 5 through port 5a; while the inlet passage 16, 16a of left hand valve 13 will be closed to cylinder 2 by the face of the valve, and the exhaust port 21 of said valve will be opened to said cylinder through port 2a, the exhaust port 23 being cut off from cylinder 4 by the face of the valve and the inlet passage 19, 19b will be opened to cylinder 4 through port 4a, the branch 19a in this case acting as a pressure balancing area.

As the machine continues to operate the tool in the normal or right hand direction the valves will continue to be oscillated so that the pressure inlet passages and exhaust ports above described will be alternately caused to register with the ports directly connecting with the respective cylinders, so as to admit pressure to and exhaust it from the cylinders at the proper time.

If now it is desired to operate the tool in the reverse or right hand direction, the direction of operation of the crank shaft 43 being reversed, the operator turns the sleeve 39, Fig. 4, thus, through the gear wheel 38 on said sleeve, engaging the pinion 37 on the spindle or shaft 37a, the disc 36 (or crank as the case may be) fixed on said shaft is also revolved so that the pin 35 on said disc bears on the lower side of slot 34 and so depresses the yoke 32, which latter, being connected to the stems 30 of the valves 13 and 14 can register with the ports 3a, 5a, and 2a, 4a, leading respectively into the cylinders 3 and 5, and 2 and 4, so that now when the valves 13 and 14 are oscillated as before described inlet passage 17, 17b and exhaust port 20 of right hand valve 14 will be alternately caused to register with port 3a, leading to and

from the cylinder 3, branch 17a acting as a balancing area, while inlet passage 18, 18a, and exhaust port 22 of said valve will be alternately caused to register with port 5a leading to and from cylinder 5, the branch 18b, in this case acting as a balancing area and at the same time the corresponding passages and ports of the left hand valve 13 (Fig. 5) will alternately register with the ports leading to and from the cylinders 2 and 4.

The working of the form of valve shown in Figs. 3, 6, 12, 13, 14 and 15, will now be readily understood. Referring to the right hand valve 14 in Fig. 6, and assuming the tool to be worked in the left hand direction as the valves are oscillated, the inlet port 61 and the exhaust passage 66b-66 will be alternately caused to register with the port leading into and out of cylinder 3, and the inlet port 64 and exhaust passage 65a-65 will be alternately caused to register with the port leading into and out of cylinder 5; the corresponding ports and passages of the left-hand valve are also caused to alternately register with the respective ports leading into and out of cylinders 2 and 4.

If now it is desired to reverse the revolution of the tool and crankshaft, the valves 13 and 14 will be moved down (by operating yoke 32, by sleeve 39 as already described) to the position in which the other set of inlet ports and exhaust passages can register with the respective ports leading into and out of the cylinders, so that now as the valves are oscillated the inlet port 62 and exhaust passage 65b-65 will be caused to alternately register with the port 3a of cylinder 3, while the inlet port 63 and exhaust passage 66a-66 will be caused to alternately register with the port 5 of the cylinder 5; the corresponding inlet ports and exhaust passages of the left-hand valve 13 will likewise be caused to alternately register with the respective ports of cylinders 2 and 4.

The arrangement of the cylinders and valves is such that at a certain part of the stroke of the pistons in the cylinders air

pressure will be acting on the pistons in two diagonally opposite cylinders, for example, cylinders 2 and 5, Figs. 5 and 6, while at the same time the air pressure will be exhausting from the other two diagonally opposite cylinders 3 and 4.

DISCUSSION.

Mr. Joseph Nasmith (who occupied the chair owing to illness of Mr. E. G. Constantine) said that the subject of pneumatic tools was an interesting one and covered a very wide ground. He thought there were many members present who were directly or indirectly interested in this question and in the various uses to which the tools were put. He would therefore be pleased to hear as many as possible take part in the discussion which was now open.

Mr. W. Lees remarked that the paper had been a very interesting one, and that they were greatly indebted to the author for it.

He would just like to ask one question in regard to the air, as to whether snow or ice formed on the tools, or whether the air was heated to prevent it?

Mr. Sam Boswell observed that the members present knew the subject was an interesting one to him, and to commence with, he admitted that he was disappointed with the paper.

He said that one of the earliest pneumatic tools was the caulker, and one reason why this was not very largely adopted was on account of them not being considered reliable, and the sellers generally informed customers that it would do so much work, instead of only about half of what they claimed for it. The author, however, had been rather modest in this respect,

but the reason of his being disappointed was because only the "Boyer" hammer was described which was probably because the author thought it was the best. Personally, he thought it was a very useful hammer for some purposes, such as a rivetter, but then no person would be able to hold such a hammer for any length of time, as it was much too heavy.

It was mentioned in the paper that caulking had been reduced to 2½d. per yard, which in his opinion was still very expensive, unless it was applicable to marine caulking. Why did the author mention seam work as an example on Page 95? Perhaps it was because the hammer was more suitable for that class of work, but as far as his experience with these hammers went, and he had seen a good many working, they gave nothing like satisfactory results, either on joint, flange, or corner work.

The author also mentioned in the paper that "a well-known boilermaker states," but does not give the boilermaker's name. They had heard statements made by boilermakers before, and whilst some of them appeared all right in conversation, they looked rather different in print, for which they were never meant.

Referring to a drill exhibited at the meeting, he said this would be absolutely useless in a boiler shop in about three weeks time, as possibly it might be all right whilst it was new, but in the class of works mentioned it could not be in that condition long.

The results obtained from the test referred to on Page 102, paragraph 8, he thought these were exceedingly good results either for hand-work or machine-work at the prices mentioned, and were very cheap indeed.

Referring to the author's visit to Messrs. Cramp & Son's shipyard, and the results obtained from them in regard to their experience with pneumatic tools, he was afraid that a good many Englishmen had not a very good opinion of

some of the American boilermakers' ideas of good work, which ideas did not very often agree with the opinions of good work required by English boilermakers. Whilst the tools might do good work for Americans, he was of opinion that they would not do for the good, solid and lasting jobs required by boilermakers of this country. A good guide for testing whether the holes were properly filled or not, was that when a rivet thoroughly filled the hole it went black at once, but if the hole was not filled then the rivet would not go black immediately. Pneumatic hammers did not fill the hole.

The author stated that unskilled labour can be employed to use these tools. but when a man had learnt how to use the tools he would become a skilled workman, therefore they would not be employing unskilled labour. The author calmly states that local conditions have to be taken into account which plays a very considerable part in the handling of the tools, and this was after stating that unskilled labour could be employed. He quite agreed with Mr. Amos that the human factor should be taken into account, but as regards the tool shown he was of opinion that it would make a young man into an old one and an old one into a cripple after they had worked these tools for any length of time.

In concluding, he said he was one of the first to experiment with the "Boyer" hammer as a rivetter, and after years of experience did not consider the "Boyer" the best.

Mr. T. Whitehead referred to the workmen who had used these tools for any length of time, as he thought the jarring upon the hands must be very serious. Could the author, therefore, give them any information on this point.

Mr. Daniel Adamson thought the paper read that night should be taken as a supplement to the author's earlier papers, which

were very complete, and altogether they give a good idea of what was being done regarding pneumatic tools.

He quite agreed with Mr. Boswell's remarks on unskilled labour, as, although the man might be unskilled in the sense that he had not served five year's apprenticeship to a trade, yet when he had learned to use a certain tool he became a highly skilled workman with that tool.

Referring to the cost of air for working the screen shaker, this appeared to agree with the experience which his firm had with pneumatic tools, that is, 12 cubic feet of free air per minute meant 2½d. per hour for the air; he would like to ask the author, however, whether the 8 to 10 cents per day per tool, stated on Page 110, in regard to the cost of air supply at Messrs. Cramp's yard was correct. In his opinion this was a mistake, and thought it should read per hour, because it did not agree with the 2½d. per hour mentioned above. The average consumption of pneumatic hammers was 20 cubic feet per hour, so that if 12ft. cost 2½d., 20ft. would mean 4d., or 8 cents per tool per hour.

As to the effect on the men his experience was that this was not harmful. As regards the wear and tear on pneumatic tools, the author had not given them any figures on this matter, but his firm found this to be at least 25% per annum on the first cost.

Mr. J. Vose agreed with Mr. Boswell and Mr. Adamson in regard to the question of skilled and unskilled labour, and thought they would have to get a clear definition of the meaning of skilled and unskilled labour in order to settle this controversy.

He would be glad to have some information respecting the rivetting done by hand and that done by hydraulic tools. In the case of pneumatic tools they had only to consider the cost of installation.

Mr. MASSEY asked if Mr. Amos could give any facts or figures concerning the efficiency of electric and pneumatic drills.

Mr. R. T. COOKE remarked that a little giant drill tried at the Ashbury works had worked very satisfactory for about twelve months.

There was one breakdown with it, caused by the workmen using a wrong kind of oil in it. The men took it to pieces; some fine drillings got into the interior and prevented the small engines working. It was taken to the fitting shop, and after four hours cleaning and a little repair it worked all right again.

Two months afterwards the makers sent one of their own men voluntarily to examine it. He reported it to be in first-class working order. There has been no further trouble with it.

Six pneumatic rivetting hammers have been at work for six months, and only require good cleaning.

His opinion, however, regarding air compressors was that if only worked to half the capacity given by the makers, and run slowly, they would require practically no repairs. If run and worked up to the maker's maximum the upkeep would be expensive.

If fitted with a good automatic governor that stopped the engines before the air safety valve opened much economy resulted, and wear and tear minimized.

Mr. J. NASMITH said that it was not always well to try and get work out of tools at the speeds which some makers represented. They were now living in an age of combines, etc., and which was Americanised, and if they required a tool giving excessive speed it would have to be well paid for; although he did not deny that it was possible to obtain the excessive outputs mentioned sometimes, he did not think it was always wise to rely definitely upon them.

He would like the author to make the different kinds of caulking mentioned quite clear when revising the paper, because there were various kinds of caulking, and it was therefore very important, especially to anyone looking through the paper for information.

With regard to the question of skilled and unskilled labour he remembered a well-known controversialist laying down a very exacting rule, that when anyone used a term he should be able to define what was meant by it. He said the difference in his opinion appeared to be between the man who had been trained, or had served an apprenticeship to some particular vocation, and a man who had not. He thought the author meant to say that they could get any man without previous knowledge of the tools, and in a very short time he would be able to use them just as well as a mechanic could do, but this did not do away with the fact that he was a skilled man, since he would be a different man at the end of the week to what he was at the beginning of the week. Although this subject did not really belong to engineering, it being more a question of language, yet he thought the term ought to be properly defined.

He would conclude by saying that the subject had not brought as many members as some, but he was sure that they were all indebted to Mr. Amos for coming from London to give them such information.

He had pleasure in proposing a vote of thanks to the author.

Mr. A. L. Mellanby wrote: Mr. Amos is to be congratulated on his paper, and thanks are due to him for bringing so important a subject before the Association.

There seems to be no doubt that pneumatic caulking, cutting, and drilling machines are each of them a success, and are profitable tools to have in most shops. It is open to doubt

however, whether pneumatic riveting machines are all that is claimed for them. Many boilermakers have objections to them, and it cannot be said that these objections arise in all cases from mere prejudice, or a disinclination to come out of the old groove.

I would also suggest that pneumatic riveting machines cannot be profitably used in a shipyard, especially on the shell plating. Taking for example the shell of a ship 450 feet long. For hand riveting it would be divided out for ten squads of riveters on each side of the vessel. These men would make all staging inside and outside, screw up and close all seams, bars, &c., they would also make their work thoroughly sound by "coming back on the rivet after two," *i.e.*, after knocking down two rivets they would return to the third, and each man give it 10 or 12 blows to fill up any space due to contraction in cooling. A good squad of hand shell riveters working under these conditions will place 2,500 $\frac{7}{8}$in. rivets in a week.

It must be remembered that a pneumatic riveter will not close anything, so that the work must be thoroughly screwed up just as in hand riveting. Also all the holes must be reamered perfectly fair instead of being drifted. A pneumatic riveting outfit must therefore include machines for riveting, holding up, reaming and paring.

If then this same vessel were divided into 10 berths for pneumatic riveting, we can easily imagine the trouble there would be in looking after the large number of flexible pipes that would be scattered about the side of the ship. Whilst the riveters are working, the shell platers are fitting the strakes above them, and the work would have to be constantly stopped to remove the pipes out of the way of the plates. It would I consider be impossible for the pneumatic riveter, under these conditions, to do as many as 2,500 $\frac{7}{8}$in. rivets per week, the men attending them making their staging as in the other case.

Mr. Amos's paper suggests the thought that the general transmission of power in workshops by compressed air is worthy of more attention. It is at least as economical as electrical transmission, and in those shops where a steam engine driving a long line of shafting is simply replaced by a large electric motor, it is likely that it would have been cheaper to have installed a large central air compressor rather than an electrical generating plant. The already existing steam pipes might have carried the compressed air, and with some slight modifications the steam engines might have been converted into compressed air motors.

Mr. E. C. Amos, in responding, said he was sure that the members knew more of the subject than they had led him to believe.

As regards Mr. Lee's question, he said they sometimes did get snow or ice forming on the drills, but it was not serious. There were occasions when it was advantageous to heat the air, but as a general rule the air was not heated. Sometimes a glove or something similar was worn by the operator.

Mr. Whitehead referred to the effect of the tools upon the workmen who had been using them; in reply he might say that recent improvements upon the hammer had reduced the percussive action upon the workman to such an extent that the effect was now practically nil.

He was sorry to hear that Mr. Boswell had been disappointed with his paper, but hoped they would all be disappointed with it if the same result was obtained, because he had raised many important points.

The first question Mr. Boswell stated was that there had been so much data given upon these pneumatic tools that it could not be relied upon, but he thought it was rather unreasonable to ask for the name of the boilermaker, since the information had been

given to him privately; but they were plain facts, and if it was absolutely essential, he would approach the boilermaker referred to, with a view of ascertaining whether the firm had any objections to him using their name. Whilst on this subject of names, he would be glad to know the name of the hammer which was superior to the "Boyer" as stated by the above gentleman. He had fought the "Boyer" hammer himself in the open market for some years, but he was now convinced that it was the best. As however he did not come to advertise any particular machine he would leave that question.

Referring to the question of caulking he said it was of course necessary to use the right sized hammer for the work required, as nobody would think of using a rivetting hammer for caulking.

Mr. Boswell is wrong in stating that the author gives 2½d. per yard as the cost of caulking with a pneumatic hammer, what he stated was that the cost had been reduced from 2½d. to ½d., which is quite different.

As regards the hammer not being able to do certain portions in a Lancashire boiler, he agreed with this in some respects, but thought however that if they could do 90% of the work with the pneumatic rivetter it was very good.

As to the cost given for drilling holes at 1s. 3d. for hand, and 3d. by pneumatic drills, this all had to be done by ratchet braces, and was in connection with gas holder work.

With regard to skilled labour he thought that the term he had used was not quite the correct one, although he knew a case where some men had been able to work the tools after only three hours teaching. Those men were entirely unskilled at the commencement, and were working the tools satisfactorily. This question had practically been the "red herring" that night, but the chairman had described what was his meaning, and this discussion proved that one could not be too careful in the use of words.

What Mr. D. Adamson had said respecting hydraulic rivets was very interesting. In a great many cases, however, they would not be able to use hydraulic rivetters where pneumatic could be used with advantage, and therefore the cost of rivetting would be less than with the hydraulic process.

Respecting the figures referred to by Mr. Adamson he thought that the cost of 2½d. per hour left a very ample margin for working the pneumatic shaker, but in respect to the figures given by Messrs. Cramps, the explanation might be found in the fact that the installation was a very large one, and the cost was calculated on the assumption that the tools were not all at work at once, so that perhaps it was not quite correct to say "8 to 10 cents per tool per day."

The question of cost of repairs was a very important one, and some makers were now giving guarantees to keep them in repair for six months and twelve months, and even if they scrapped the tools as the end of twelve months and bought fresh ones, they would be saving money.

He was sorry he could not give the difference of cost between the hydraulic and pneumatic tools.

As regards the cost of repairs mentioned by Mr. Cooke, he agreed with him in stating that in nine cases out of ten people would put in compressors which were a great deal too small for the purposes required.

In comparing the weight of the electric and the pneumatic drills, he said the former were very much heavier than the latter, though some users claim that for certain purposes the electric are better suited than the pneumatic. Personally, he was in favour of everything portable. He also thought that the cost of repairs to the electric drill was very much higher than pneumatic.

Respecting Mr. A. L. Mellanby's written communication, the author wishes to state:—(1) That with regard to boilermakers, pneumatic rivetters are daily growing in favour with them, and

they are coming into use very rapidly for this class of work. (2) That with regard to shell rivetting, Mr. Mellanby is evidently not aware of what is actually being done with pneumatic shell rivetters at the present time, since not only would it be possible for a squad of rivetters using pneumatic appliances to close 2,500 $\frac{7}{8}$in. steel rivets in a week under the condition that Mr. Mellanby states, but they would close considerably more than this number of rivets and would obtain better results than by hand-rivetting.

He concluded by thanking them for the vote of thanks and for the attention given.

2 Plates follow illustrating this Paper.

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UNIV. OF MICH.

ND APPLIANCES.

Tripod Type.

Low-Frame Post Machine in position.

Low-frame Post Machine shewing portability.

of "Hanna" Screen Shaker.

UNIV. OF MICH.

THE PREMIUM SYSTEM OF REMUNERATING LABOUR.

READ SATURDAY, 4TH APRIL, 1903,

BY

Mr. JOHN ASHFORD, M.I.Mech.E.,

MANCHESTER.

The successful working of a manufactory depends largely upon the system of remunerating workmen for their labour. Especially is this the case where such workmen have to attend the working of costly machinery, the output from which depends to a considerable extent upon the workman's ability and his attention to his work. This may be said to be essentially the conditions in an engineering workshop where a large portion of the work is done upon machine tools.

We may take it that one of the first commercial principles of manufacturing is, that, with a given selling price for the article produced, a certain output must be reached and exceeded, before expenses are covered in the particular manufactory and the making of profit begins; and, that having passed that point in output, the proportion of profit increases rapidly as the output is enlarged.

The scheme of remuneration will undoubtedly militate towards increasing or retarding the production and, therefore, will have a very considerable effect upon the business.

The chief systems that have obtained up to within recent years, have been either day work with payment by the hour or piece work. If payment is by the hour, the workman has little

inducement to press his machine to produce the maximum output, and the extent of his efforts is generally limited to the amount he considers will satisfy his employer, and a satisfactory output is usually only obtained by "horsing" on the part of the staff.

There are but two ways of getting an individual to exert his maximum effort; firstly, by driving, and secondly, by offering inducement. While many are tempted to adopt the driving principle it cannot be considered satisfactory to anyone concerned, certainly not to the person driven. It is possible only to drive down stipulated roads, and the driven are not likely to use their brains in seeking for short cuts. On the contrary, create a sufficient inducement, and the individual will use his wits in devising means to reach the objective by easier ways and in shorter time.

In the case of remuneration by the hour, there is but little in the nature of inducement beyond the retention of the situation. The only real inducement is the somewhat uncertain one of a possible increase in the rate of remuneration, and this, normally, is very remote when a man is already receiving what is known as *full rate*.

In the case of piecework, an inducement is created of a somewhat doubtful character, for the man is aware that if he exerts himself to the extent of obtaining more than a limited increase upon his normal wage, the piecework price will be reduced. The real tendency of piecework, unless administered by a very competent staff is, then, rather the reverse of what was intended, for the worker will be careful that he does not earn more than, say, time-and-a-quarter. Thus it is possible that instead of being a reasonable inducement to the worker, it may in effect have a decidedly retarding influence. It might be argued in favour of piecework that if prices are correctly set, such retardation is impossible. Such an argument is obviously

based upon the assumption that finality has been reached in the matter of speed of production, or an acceptance of the unsatisfactory principle of piece-cutting. Another serious aspect of piecework, is, that it is based upon a system of bargaining, for it pre-supposes that a price per piece is agreed upon between the worker and the employer, by which the former agrees to do the work at a certain price. Such a species of bargaining places the employer and the worker at two opposite extremes, and this naturally leads to a species of antagonism that engenders the reverse of friendly feeling. The effort of the employer to get his work done cheaply and so to place himself in a better commercial position, is thus likely to cause estrangement between his workers and himself. It is a matter of history that many strikes have resulted from the estrangement originating in differences as to the fixing of piecework prices. The chief failing point in piecework may be said to rest in the fact, that an alteration in the price in favour of either of the contracting parties is bound to be to the detriment of the other, which means a clashing of the interests of the employer and workers.

It will no doubt be accepted without controversy that providing a system of remuneration is found that establishes a community of interests between the employer and his workers, whereby it is to the interests of both to increase the output of the establishment, there will be harmony of feeling and a much greater probability of attaining the desired results.

Providing that the worker finds it is to his personal interest to get the maximum amount of work from his machine, no doubt he will take steps to get it, and if he finds another able to obtain better results than he in a different way, he may be trusted to adopt the other's methods. If he finds that by thought and scheming on his own part, he can do better for himself, he again may be trusted to look after the matter.

Various methods have been tried for giving the worker this personal interest, such as profit sharing, differential piecework, and more recently the premium system of remuneration.

As to profit sharing—when applied to the ordinary worker it may be said to have generally failed, for the advantage to be gained seems to him somewhat problematical and remote, as his best efforts may be nullified by the fault or mismanagement of others.

Differential piecework is a partial solution of the problem, of which the possibilities are, in the Author's opinion, too narrow; and, while an improvement upon piecework, it suffers from some of its faults.

The premium system is of more recent development; and, when worked in a proper manner, undoubtedly creates that inducement to call forth the best efforts of the worker. This system may be said to be a method of remuneration which places a premium upon effort and intelligence, the greater the effort and the higher the intelligence displayed by the worker, the more becomes his personal return. It may further be said to be a method of remuneration which ensures to the employer a reduction in prime cost, of increasing magnitude as the worker's return becomes greater, thus unity of interest is created.

The Premium System as it is now understood, was introduced by Mr. F. A. Halsey, at the works of the Canadian Rand Drill Company of Sherbrooke, in 1890. His scheme was to take the time that a job had previously taken by daywork, and offer a premium at the rate of one-third a man's wage per hour for each and every hour that he saved. Thus, the man was paid for his time at time rate, and was given, as an inducement to shorten the time of doing the work, a premium equal to one-third of the time saved, at his own rate. In establishments

where work is continually repeating, and where cost keeping has been sufficiently detailed to form exact records of times spent by daywork upon the various jobs, this general scheme upon a daywork base may be employed, providing that the hourly bonus is not too high. It has been found by experience that the time taken to do certain work by the hour may be reduced to an unexpected extent when an inducement is given the worker, consequently, if the hourly bonus is too liberal, the employer when he finds how little time is really necessary to do the job, will be strongly tempted to reduce the allowed time. This temptation however, must be resisted, as the fact of cutting would destroy the harmony existing between himself and his workers, and thereafter, he would fail to get their best efforts from them.

The more usual plan followed is for the worker to be paid his hourly wage, and to work against a time set by the management, called a standard time. If the worker completes the work within the standard time, he is paid a premium equal to some proportion of the difference between the time taken and the standard time. There is no recognized proportion that constitutes the premium, any more than there are any recognized standard times for doing jobs, apart from those in each individual establishment.

The original idea of premium working may now be found in several different forms, although the underlying principle is the same. Probably the most important diversion from the original Halsey scheme, is that introduced by Mr. James Rowan of Glasgow, the chief point of variation lying in the method of dividing the difference between the standard and the actual time. Whereas in the original Halsey scheme the difference was divided in a pre-arranged proportion, in the Rowan application, the premium consists of a percentage calculated upon the actual time, in the proportion that the saved time is a percentage of the standard or allowed time.

Thus if the worker completes his job in 20 % less than the standard time, he is paid his hourly wage for the actual period, plus a premium of 20 % of the same. The practical difference between the two methods is, that the premium reward to the worker upon the Rowan system is greater in proportion to his effort for the lower savings that are effected, and less in proportion as the saving becomes greater.

By the Rowan method the worker receives the greater proportional reward when the time is reduced to 75 % of the standard.

In the Halsey method the return of the worker is somewhat less for the lower proportion of saved time and greater for the higher proportion.

The comparison of the two methods is more clearly shown by the aid of a diagram. See Diagram 1, Plate I.

In this diagram, several curves are plotted that bring into comparison the Halsey 50 % premium system, and the Rowan system. For convenience of comparison it is assumed that the daywork or standard time is 100 hours, and the curves are plotted on the assumption that there is a steady reduction, by the worker, of the actual time taken to do the job from 100 hours to nothing in order to make the diagram complete. The upper pair of curves starting from 100 indicate the actual cost of the article as the time is reduced. Both methods show a steady reduction of cost, and it will be observed that the Halsey system gives the lower cost until such time as the worker has reduced the actual time to one half. For time savings in excess of 50 % the Rowan system shows a lower wages cost.

Turning now to the workers side of the question. Starting from zero, the two lower curves show the actual premium, expressed in hours, that is paid to the worker for his efforts in reducing the time on the job. The lines representing the two systems will be seen to cross at the middle, the first half

indicating that the Rowan system gives the larger premium to the worker, whereas the Halsey system gives the greater premium in the higher savings of time. The Author is inclined to think that the worker would favour the Rowan system as giving him the greater return for the least effort, although the inducement cannot be said to be great after the 50% is reached.

The worker would probably look askance at the fact that if he saved over 50% of the time, his actual balance on the job decreases, although the percentage to his working time steadily rises. The Halsey method on the contrary, offers great inducement to the worker to aim for the higher time savings, as offering him return commensurate with the higher tension of his effort. The two curves springing from zero and mounting to the higher parts of the diagram, represent the percentage of the premium to the actual time. The rapid rise of the Halsey percentage over the 50% point is a matter for observation, and in the opinion of some, this constitutes a danger to the success of the system.

Considering the points in common between the two systems, perhaps the most important, and one upon which full stress should be placed, is the idea of taking a standard time for a given job, that shall be unalterable so long as the same method of machining and quality of machine tool are used. The success of the whole system depends upon the continued adherence of the parties concerned to this principle, as forming the basis of mutual confidence. There is no necessity, neither inducement, to a reasonable employer to desire or to try to cut down the standard time when once it is fixed, even though the worker should obtain premium running into high percentage, when in spite of that fact, the prime cost of his article is less. This is one of the important differences between premium and piecework, for with the latter, whatever balance the worker makes, the wage cost to the employer remains the same until such time as he cuts the price. What matters it, if, under premium, the

worker makes high wages? The concern of the employer or manager is to make profit, not what it is necessary to pay away in order to make that profit.

The next point is, that in spite of the fact that the system may be based upon a standard rate of wage, it opens the door for individual merit in the worker to find recognition and reward.

A further feature which has grown up around the premium system, is the principle that the worker is guaranteed his hourly wage without reduction, whatever the time in which a job is completed, and that there is no debt. It is a common experience in piecework that, when a worker from any cause, gets into debt and sees no prospect of obtaining extra remuneration on other usually paying jobs, he loses heart and allows other work to slip into debt likewise, until there is no chance of clearing himself by other balances. He then either leaves his situation to start free of encumbrance elsewhere, or the debt has to be forgiven. With premium there is no debt, each job, which may consist of one or more articles, stands alone in its reckoning; and, although in a previous job he may have been unfortunate and have run behind, he starts clear with renewed opportunities and fresh inducements to put forth his efforts.

In the case of piecework, it may be necessary to give various prices for the same job to differently rated men; not so, however, with premium, as time counts the same whatever the rate, with special exceptions.

In establishments where overtime or night shift may be worked, piecework contracts occasion much discontent, for the price is usually kept the same although the rate of pay becomes time-and-a-quarter or time-and-a-half. In the case of premium one hour counts one hour, whether by day or night. The reasoning associated with this principle, is, that the overtime is worked by the employers' desire and especially for his

benefit, and that, therefore, such extra cost as it entails should be met by him.

Queries may be advanced as to how the premium system may be successfully worked in such comparative instances as where:—

A. One man works one machine.

B. One man works two machines.

C. One man works three machines.

D. An apprentice boy works one machine.

E. An improver works one machine.

F. One man and one boy work two machines.

The Author has met these several cases in what proves to be a satisfactory way, basing his reasoning upon the ideas that it is desirable, firstly, that from the employers' point of view one man should work several machines; secondly, that from the workers' point of view, if he operates several machines, he shall have a sufficiently increased return as an inducement; and thirdly, that a boy, inexperienced in the use of a machine, requires more time to get through a given piece of work.

Considering—

A. That one man working one machine is allowed an amount of time equal to unity 1

B. The time allowed for work on each of two machines shall be $\frac{2}{3}$ds. that allowed in case A giving a total for the two machines of... ... $1\frac{1}{3}$

Note.—Where an operator works several machines his time is evenly divided when booking to the work on each machine. The extra one-third time allows a margin for the slight loss of time on each machine by divided attention, and leaves a margin for extra premium.

C. The time allowance for each machine is, in this case, one-half that of case A giving a total for the three machines of ... ... $1\frac{1}{2}$

D. Instead of changing the time allowance for an apprentice the case is met by charging to the job one-half of the time taken. (half-time charged) 1

E. For an improver who is earning less than a sovereign a week, the time allowance remains constant, but the time taken is charged as three-fourths ... ... ($\frac{3}{4}$ time charged) 1

F. To meet this case, the time is initially taken for each machine as in case A, and three-fourths of that is allowed, making a total for the two machines of ... ... $1\frac{1}{2}$

Note.—As an inducement to a man to partner with a boy in this manner, the boy charges his time at one-half, the same as an apprentice working one machine, and to obtain a suitable division of time, both the man and the boy book a half of their chargeable times to each machine.

In the average establishment, certain degrees of accuracy must be obtained for the work to be satisfactory, and it is necessary to have some form of inspection to decide when a sufficiently high standard has been reached. The standard required should be made as clear and distinct as possible, and there should be but little opportunity for the exercise of personal opinion as to whether the work is or is not passable. To establish a deciding line, it is generally advisable to have some form of limit-gauge system of measurement, with the clear understanding that if the job fails to come within the limitations it may be scrapped, and upon scrap no premium is paid. This understanding may be supplemented by an arrangement to the effect, that, although a job is outside the allowed limitations, it may, by the expenditure of further time and money in other processes by way of correction, be made

good enough, one-half premium only will be paid, the remaining half going towards the cost of making the job usable.

In the event of material proving faulty to the extent of making the job of no value for its object, it constitutes a loss to the employer to the extent of the hours spent upon it, and the worker receives no premium. This remark does not apply to any completed machining operations prior to the one during which the fault declared itself. This is a perfectly fair arrangement, for the operation would cease at the discovery of the fault, so would never be completed.

When an employer is considering the advisability of introducing the premium system into his establishment, he would naturally formulate queries as to what it entailed in the way of administration, and what might be the best methods of procedure. The Author would here venture a word of warning. Do not touch the premium system unless fully convinced as to its advisability and adaptability to the case, and then only with a firm determination to carry it right through.

The initial work is both arduous and costly as compared with some other systems. It also takes time to get into working condition, and the work of organization must be thoroughly tackled. The whole work should be under the direction of a competent man, and there should be no attempt to half do it. To put the work of time-setting upon the frequently overburdened shoulders of foremen would be fatal to its success, as any hurried estimating of times is certain to cause dissatisfaction to either the worker or the employer. The fact that the times when set are to be standard, means that the machining operations must be carefully considered, and times assessed for every operation that constitutes the whole work upon the job.

Full records of the detailed time-setting should be preserved for reference, as should also the times required to do the work, as this becomes valuable information for future guidance. This,

in an establishment of moderate dimensions, means an amount of work which will call for a staff of trained men constituting a time-setting and recording department.

The time-setting sheet used by the firm with which the Author is connected, is shown in Appendix A., with illustrations of its use on two typical jobs. Examination of these will show that the work of time-setting is done in a methodical way, with due consideration of the feeds and speeds of the machine that are possible as applied to the particular job.

It is found by experience when observing the time spent in various ways upon particular pieces of work, that of the total time required to do the work, a certain proportion is, of necessity, spent upon the work that may be broadly classed as handling, and that the remainder of the time is spent in actual cutting operations. The handling time would consist of preparing the machine, lifting in the work, setting tools and grinding same, gauging, etc., and that with different kinds of jobs, this handling time may be of differing percentages of the total cutting times, varying between wide limits.

When such observations are made and recorded it very much simplifies the work of time-setting, for it then becomes merely necessary to work out the surfaces to be tooled, and the time required to machine them with given cuts, feeds, and speeds. Of the net tooling time so obtained, the handling percentage is taken and added thereto, producing a total which indicates the net time in which the job can be done. Upon this time, a further addition should be made in order to give the worker an opportunity of making a suitable premium. When considering this added time, in general, it is not advisable to cut things too fine. It rather pays to err on the side of generosity than to be niggardly in this matter, as it is generally found that with finely cut time, the actual time spent upon the job by the worker is greater than if more liberal time is set.

This no doubt is due to the moral effect produced. Thus the Author would repeat, that considering all things, it pays to be somewhat liberal in time-setting, rather than the reverse.

As an aid to time-setting, the Author would indicate a few ways of easing labour. As frequent reference has to be made to the feeds and speeds of machines, a carefully compiled series of tables should be prepared of every machine tool with its capacity, feeds and speeds, together with any remarks as to its tool equipment, faults, etc. See Appendix B.

When a series of similar jobs of varying sizes have to be machined, it is convenient to take some proportionate dimension and plot along the abscissae of a diagram and the allowed times as ordinates, producing a curve of times for a given machine, taking the extreme and several intermediate sizes. From such a diagram other times may be read as required.

For instance, for plain turned jobs of varying lengths and diameters, a multiple of the diameters into lengths may be set off along the horizontal of a diagram, with allowed times as ordinates, as in Diagram 4, Plate II. Such diagrams may be extended very considerably as in Diagrams 2 and 3, Plate I., which the Author has prepared for time setting on turret lathe, dealing with bar work, and in Diagram 5, Plate II. It is possible with such diagrams, to allow for the various failings or facilities for production of the different machine tools available for the class of work, by adding other lines of proportionate values. This is clearly illustrated in Diagrams 4 and 5, Plate II.

Another little convenience is Barth's time setting card. If this is modified to suit individual machines by adding an extra circle and pointer with lines indicating cone steps, it is possible to drop immediately upon the cone steps required to give the nearest cutting speed to that best suiting the job, together with the time required for machining.

No doubt members will readily think of other labour saving methods of simplifying the work of time setting.

For filing the standard times and records, probably a suitable card system has advantages over books. Both the front and reverse of a card arranged by the Author for this purpose are illustrated in Appendix C.

As the whole matter is based upon time, some suitable means of checking the starting and finishing times must be employed to ensure correct bookings. This may be done upon a job card or progress ticket such as is illustrated in Appendix D. This ticket is issued to the workers by a ticket clerk who fills in the necessary information respecting the job, together with the man's name, number, and the machine number, and he also punches the ticket in the square corresponding to the starting time, differently shaped punches indicating a.m. or p.m. At the completion of the job the ticket is again punched in the portion of the ticket on the reverse marked finishing time. This enables the time spent on the job to be calculated. In the event of a job being suspended from any cause, a note to that effect is made upon the ticket and the time of resumption is also stated.

The advantages of the premium system of remuneration have only been partially stated when the bald system has been explained, for its effect in various other directions is decidedly pronounced. From a managing point of view, it is of great assistance in watching expenditure, and also in observing the capabilities and smartness of the workers, for by the tabulation of results, attention is spontaneously called to those jobs that have taken excessive time.

A full use of the time setting department is also of advantage in estimating the expenditure that is likely to be incurred on a given machine, and if the whole work of time setting is done

from drawings in advance, it would give an opportunity to alter designs to cheapen cost if found necessary.

The full commercial advantage to be reaped by the aid of the premium system can only be realized by glancing at other results. Take for instance the prime cost of a given article. This does not merely include the workers' wage but other items which may possibly represent much more to the firm, for instance the actual hourly cost of a machine. The very fact of having a machine within a workshop means expense, and each hour a job is upon a machine, costs an amount equal to the workers' wage, plus what may be called the machine cost. This machine cost would comprise the interest on capital it represents, its depreciation, the power to drive it, its share of the interest on building proportionate to floor space, building depreciation, shop lighting and cleaning and say works' management, these items comprising a portion of what is frequently lumped under the heading of "oncost." This charge, that can be put against the machine, will vary according to its initial cost and the room it occupies in the shop, and it may range from a few pence per hour for a small cheap machine, to several shillings per hour in the case of more important machines. Thus the effect of a reduced time by premium may cause direct saving of machine cost, and it will also make it possible to get more work from the machine, thereby obviating costly overtime or increasing the annual turnover.

A further item that is here suggested is, that with a given establishment and tool equipment, it becomes possible to get an increased output and so perhaps converting a hazardous concern into a successful one.

There is still another matter to be observed by expediting the progress of work through the shops, contracts may be filled more quickly, capital is locked up a shorter time in progress work and items pass into the day book at an earlier date.

With an effort to show what it means commercially, the Author has prepared a series of diagrams showing the effect upon "oncost" under certain assumed average savings of time, and also, the probable effect upon the profit and loss account.

Investigating the effect upon "oncost" and profit making, it becomes necessary to deal with *assumed* proportions of figures. For the sake of following some consistent form of reasoning, and while indicating generally the *probable effects*, the *actual results* will entirely depend upon the particular business to which the system might be applied. That his reasoning may be readily followed, the Author has indicated upon Diagram 6, Plate III., what he has assumed as composing that somewhat broad term "oncost," and, that the information may be of some value, he has set it out in the form of percentages. Starting with an assumed normal output with a given plant prior to the introduction of premium system, and supposing that the effect of premium is to increase output, the diagram has been plotted to an ultimate increase of output of 100%.

The first item considered as contributing to "oncost" is depreciation. This is usually placed at a certain percentage of the plant capital; therefore, its line of representation will be horizontal showing no increase. Probably it would be wisdom to allow an increased rate of depreciation to compensate for extra wear and tear upon machines.

The next item is works' management. This is assumed to increase by 10% to allow for the cost of time setting department.

Commercial management is considered as likely to increase to the extent of 10%.

The demand for fuel would not be directly proportionate to the output and is placed at a 60%. increase.

Assuming that selling expenses would increase, allowance is made in the section of "oncost" placed under the general heading of trade expenses, to the extent of one-third.

General shop labour would no doubt increase, by the extra amount of work to handle. This increase, however, will not be in direct proportion to output, as many types of labour such as crane drivers, sweepers, &c., would remain normal. Thus, here the increase is placed at one-third.

The last item under the head of manufacturing charges would comprise many odd items and it is difficult to say whether the increase would be proportionate. Probably it would not, yet for the sake of broadening the estimate. these charges are considered at double their normal.

Summing these up to a total, when the turnover is doubled, the probable increase of total "oncost" becomes 184% of the original, and for the sake of following the line of argument, it is assumed to have a proportional increase for lesser additions to turn-over. As indicative of the comparison between "oncost" and output, an extra line is introduced into the diagram to show the "oncost" percentage decreasing in relation to sales as the turnover rises. It will be observed to drop 35% within the range included in the diagram.

In order to judge the probable effect upon profits, Diagram 7, Plate III., has been prepared. Referring to Diagram 1, Plate I., the total wage including premium, if the whole plant is occupied, may be observed to rise as the manufacturing time is reduced per article, but to a lesser extent than the enlargement of output. This increase in the Rowan system is represented by a diagonal springing from zero. When the time upon the article is reduced to 50%, the premium by both systems mounts to 50% and the output with the same producing plant, working full time would be doubled.

In Diagram 7, Plate III., the cost of production in wages plus premium is set out as with normal output and as increased by the aid of the premium system. The productive wages are considered as normally amounting to 25% of the turnover. The material is assumed to be 30% of the turnover and to increase in direct proportion. The "oncost" is considered to normally constitute 30% of the turnover, or 120% of the productive wage. This latter percentage will, of course, vary with different establishments. The balance constituting profit is then placed at 15%

Allowing the various increases as discussed and plotting the lines accordingly, enables us to see that the proportion of profit rises very rapidly as the turnover is increased by the aid of the premium system and in spite of the high balances that become payable to the workers.

It will be observed that in the case of an establishment that nominally fails to make profit, although paying its way, an increase of production of 10% represents a sufficient profit to pay a dividend of 4 or 5%, whereas a 20% increase, which is not by any means difficult to obtain so for as works' output is concerned, will represent a reasonable profit with something to carry over.

To further illustrate this point, a small Diagram 8, Plate III., is set out. It may be argued that these various diagrams and figures have been prepared, starting with the simple assumption that the introduction of the premium system is bound to be accompanied by a reduction in the producing time and the paying of substantial premiums to the workers. In response, it is merely necessary to quote from experience.

The Author has found that reductions in time and cost have been more than expected, for it is by no means uncommon to find work costing as much as 80% less when worked by premium than it had hitherto cost by piece-work.

As indicative of what can be done the following instances are quoted:

Work. A set of three cylinders for a triple expansion engine.
Process. Planing.
Machine. No. 147. Machine cost per hour 8/-

	Time Allowed	Time Taken	Hours Premium	% Balance	Total Wages and Balance			Total Machine Cost			Total Cost		
					£	s.	d.	£	s.	d.	£	s.	d
1st	207	150¾	28½	18·7	5	18	2½	22	18	0	28	11	2½
2nd	207	125	41	32·7	5	9	7½	18	15	0	24	4	7½
3rd	207	121	42¾	35·1	5	8	5	18	3	0	23	11	5

Increase in man's balance 1st time from 18·7 % to 32·7 % = 14·0 %
,, ,, 2nd ,, 18·7 % to 35·1 % = 16·4 %
Saving in wages cost 1st time - - - - - - = 7·7 %
,, ,, 2nd time - - - - - - = 12·5 %
Total saving in cost to firm 1st time £4. 6s. 7d. - - = 15·0 %
,, ,, 2nd time £4. 19s. 9½d. - = 17·5 %

Work. Bedplate. Process. Planing.
Machine. No. 147. Machine cost per hour 8/-

	Time Allowed	Time Taken	Hours Premium	% Balance	Wages cost, and Balance			Total Machine Cost			Total Cost		
					£	s.	d.	£	s.	d.	£	s.	d.
1st	91	59½	15¾	26·5	2	9	8	8	18	6	11	8	2
2nd	91	54	18½	34	2	7	10	8	2	0	10	9	10
3rd	91	53	19	35·8	2	7	6	7	19	0	10	6	6

Increase in man's balance 1st time from 26·5 % to 34·2 % = 7·7 %
,, ,, 2nd ,, 26·5 % to 35·8 % = 9·3 %
Saving in wages cost 1st time - - - - - = 6·0 %
,, ,, 2nd ,, - - - - - = 7·1 %
Saving in cost to firm 1st ,, - - - - - = 8·1 %
,, ,, 2nd ,, - - - - - = 9·5 %

The above items were selected as being worked upon a planing machine where the cutting speed cannot be varied as in a lathe, and reduction in time can only be effected by increasing the cuts and in the handling.

Another planing job on an old machine progressed as follows :—

Under Piecework Cost		25/-	-	Balance 25 %
1st time under Premium System		17/9	-	,, 30 %
2nd	,, ,,	17/2	-	,, 33·3 %
3rd	,, ,,	16/8	-	,, 45 %
4th	,, ,,	16/2	-	,, 52 %

For comparing the results of piece work and the premium system as affecting costs, the Author has prepared a sheet of results, showing at the same time the percentage premium paid to the worker. See Appendix E. These jobs were done as nearly as could be ascertained on the same machine.

With a view to ascertaining whether the men are losers by the change, the Author has summed the whole of the work done by premium at the works of the firm named, and finds that the average percentage of balance paid from the start is 20%, while for seventeen consecutive weeks it has averaged 25·5 %.

The success of any scheme of remuneration or working depends largely upon those who administer it, and because it is successful in one place is no proof that it will be so at another. Even as in the case of piece-work, while it may produce satisfaction to both workers and employers at one place, it may, if not administered equitably and fairly, fail to come up to expectation at another. Honourable fulfillment of all agreements, especially regarding the standardised times, should be the key-note of its administration.

In conclusion, the Author would respectfully submit to his fellow members for their consideration, the thought that one of the most important principles of management, is, to create unity of interests between those whose help is needed, even in the most menial capacity, and the employer; and, that this can best be done by instituting such a method of remuneration as is provided in the Premium System.

APPENDIX A.

SPECIMEN TIME SETTING SHEET.

Machine No. 104. *Sheet No. 1,134.*

Job No. 12.—Crankshaft.

Catalogue No. 041. Drawing No. 5,560. Date 23/12/02.

Turning (Previously roughed on body).

Process.	Tool.	Feed.	Speed.	Cut.	Finish	Time.	Remarks.
1 Centring and setting-up						4·0	
2 Turning ends for throws		8	A 2			2·0	
3 Lifting out & setting-up throws						2·45	
4 Balancing, etc.						3·15	
5 Roughing H.P. pins and webs		8 & 16	B & A 2	1/8		5·30	
6 Finishing do. ..		8 & 16	D 2		No. 1	3·0	
7 Radiusing do. ..		Hand	B 2			1·15	
8 Filing out oval and lapping..					No. 1	5·0	
9 Change centres to L.P. pin ..						2·0	
10 Roughing L.P. pins and webs		8 & 16	B & A 2			5·30	
11 Finishing do. ..		8 & 16	D 2			3·0	
12 Radiusing		Hand	B 2			1·15	
13 Filing out oval and lapping .					No. 1	5·0	
14 Changing centres to L.P. 2 ..						2·0	
15 Roughing L.T. pins and webs		8 & 16	B & A 2			5·30	
16 Finishing do. ..		8 & 16	D 2			3·0	
17 Radiusing do. ..		Hand	B 2			1·15	
18 Filing out oval and lapping..					No. 1	5·0	
19 Changing centres to webs H.P.						2·0	
20 Roughing H.P. webs		8	A 2			1·0	
21 Finishing.....		8	D 2		No. 5	1·0	
22 Repeat 19, 20, 21, twice . ..						8·0	
23 Change centres to body.....						5·0	
24 Turning body rough		8	A 2			5·30	
25 Rough webs outside		16	A 2			4·0	
26 Reducing radii		Hand	A 2			2·0	
27 Finish body...		8	C 2		No. 1	9·0	
28 do. webs outside		16	D 2		No. 5	6·0	
29 do. 8 radii		Hand	C 2			2·40	
30 File and lap body					No. 1	9·30	
31 Change for end..						·45	
32 Rough do.			A 2			2·0	
33 Finish do.			A 2			1·0	
34 Lap do.					No. 1	1·30	
35 Add for grinding, gauging, craning, etc.....						13·30	
						145·40 Net time	
Add allowance							
If loose steel centres required, add for boring-up, etc						11·0	

Finishes.

No. 1. Best, accurate to ·001in.....Time Fixer .....
No. 2. Good, accurate to ·002in.
No. 3. Medium, accurate to ·005in.
No. 4. High Polish.
No. 5. Left broad cut or water.
No. 6. Rough Machine.
No. 7. Left ·010in. full for grinding.
No. 8. Left for forcing fit.

APPENDIX A.

SPECIMEN TIME SETTING SHEET.

Machine No. 1. *Sheet No. 859,*

Job—Distance Piece.

Catalogue No. 250. Drawing No. 4,154. Date 19/11/02.

Boring.

Process,	Tool	Feed.	Speed.	Cut.	Finish	Time.	Remarks.
1 Roughing 2 cuts		16	B 2		No. 6	156	
2 Finishing 1 cut		12	B 2		No. 1	52	
3 Face-up		Hand				15	
4 Chamfer 2 places						30	
5 Bore for plate, 2 cuts						20	
6 do. finish					No. 3	10	
7 Recess for plate						40	
8 Handling						150	
						473min net=8hrs say	
Add allowance for balance							

Finishes.

No. 1. Best, accurate to ·001in.....Time Fixer.....

No. 2. Good, accurate to ·002in.

No. 3. Medium, accurate to ·005in.

No. 4. High Polish.

No. 5. Left broad cut or water.

No. 6. Rough Machine.

No. 7. Left ·010in. full for grinding.

No. 8. Left for forcing fit.

APPENDIX B.

SPECIMEN SCHEDULE OF MACHINE TOOL DATA.

VERTICAL BORING MILLS. *Sheet No. 7a.*

Machine No.	Description.	Capacity. Dia.	Capacity. Depth.	No. of Speeds on C. S.	Speeds (revs per min.) Double Gear.				Speeds (revs per min.) Single Gear.				Feeds (per inch).					Remarks.
155	Vertical Boring Mill double gear $4\frac{1}{2}$ to 1	Ft. In. 5 0	Ft. In. 3 6	1	$1\frac{1}{2}$	$2\frac{1}{4}$ $5\frac{1}{2}$	3	4	7	10 24	$13\frac{1}{2}$	18		$2\frac{3}{4}$ 12	4 16	8 32		Gear feed.
	Vertical Boring Mill double gear 6 to 1	3 3	2 6	1	$1\frac{3}{4}$	$2\frac{1}{2}$ $7\frac{1}{4}$	$3\frac{1}{3}$	5	11	$15\frac{1}{2}$ 44	22	31	2 10	$2\frac{1}{2}$ 12	3 16	4 32	8	Gear feed.
122	Vertical Boring Mill double gear 16 to 1 and 4 to 1	4 0	1 10	2	$1\frac{1}{2}$ $1\frac{3}{4}$ 6 7	2 $2\frac{1}{2}$ $8\frac{1}{2}$ 10	3 $3\frac{1}{2}$ 12 14	4 5 16 20	24 28	34 40	48 64	64 80	$2\frac{3}{4}$ 12	4 14	5 16	8 32	10	Friction feed.
135	Vertical Boring Mill with turret, double gear 6 to 1	2 8	0 11	2	$2\frac{3}{4}$ $3\frac{3}{4}$	$4\frac{1}{2}$ 6	7 $9\frac{1}{2}$	11 15	16 22	27 36	42 56	66 90	4 10 32	$4\frac{1}{2}$ 12 48	5 16	6 20	8 24	Friction feed.

APPENDIX B.

SPECIMEN SCHEDULE OF MACHINE TOOL DATA.

MILLING MACHINES. *Sheet No. 13.*

Machine No.	Description.	Spindle. Dia.	Spindle. Trav.	Will admit in. Dia.	Will admit in. Depth.	Traverse of Table. Longitudinal.	Traverse of Table. Transverse.	Speeds (revs. per min.) Double Gear.	Speeds (revs. per min.) Single Gear.	Feeds (per inch).	Remarks.
69	Vert. Milling Machine double gear to spindle 4 to 1	In. 3	In. 7	Ft. In. 3 0	In. 12	Ft. In. 2 0	Ft. In. 1 6	21 34 54	84 136 216	96 72 128 172	With Circular Table.
	Vert. Milling Machine double gear 6 to 1	3½	12	2 9	16	4 4	1 3	10 13 18 With slow C.S. speed 24 32 44 Fast C.S. speed.	60 80 109 Slow C.S. Speed. 146 200 272 Fast C.S. speed	0·44 0·68 0·9 1·0 1·8 1·8 1·48 1·7 2·0 2·25 2·5 3·0 3·43 3·7 5·12 7·5	Feeds driven from countershaft with circular Table, &c. (Two of these Machines).
	Hor. Milling Machine double gear 6 to 1	3½				3 6	0 8	16 21 24 32 36 48	96 126 144 192 216 288	5 9 10 15 18 24 27 30 34 38 48 50 54 68 76 100	Feeds from spindle given. Feeds from C.S. not belted. (Two of these Machines.)

APPENDIX C.

FILING CARD FOR TIMES AND RESULTS.

PREMIUM TIME CARD.

100, 103, and 105 Catalogue Number.

12 Engine Size.

Drawing No. *5631.*

Description of Work *Set of 3 Cylinders.*

Operation *Planing.*

On Machine Number *147.*

Time allowed per piece *207 hours per set.*

Ditto for preparing Machine *included.*

Progress ticket No.	Quantity.	Per cent Premium.	Time tak'n per piece.	Progress ticket No.	Quantity.	Per cent. Premium.	Time tak'n per piece.
9315	*set*	*18·7*	*150¾*				
13773	*do.*	*32·7*	*125*				
15131	*do.*	*35·1*	*121*				

APPENDIX D.

Progress Ticket as issued to a workman.

FRONT :

Progress Ticket No. *17861.*

Machine No. *203.* Order No. *11037.* Drawing No. *3549.*
Day Man's No. *511.* Name *G. Brown.* Rate of Wages_____
Night Man's No._____ Name _____ Rate of Wages_____
Work *6 Connecting Rods.* Size *3.*
Process *Slotting Complete.*
Date given out *28/3/03.*
Date Finished _____ Day Wages_____
Hours Allowed *60.* Night Wages_____
Hours Taken_____ Total Wages Cost _____
Machine Cost_____
Total Cost_____
Marker Off_____ Checker_____ Posted by_____

Starting Time: All entries on this Card to be made in Office.

12	½	1	½	2	½	3	○	½	4	½	5	½	6
6	½	7	½	8	½	9		½	10	½	11	½	12

REVERSE :

Daily Time Spent on Job.

To be entered from ○ Time Sheets by Clerk.

Day Man.									Night Man.					
Date	No.	Hours	Date	No.	Hours	Date	No.	Hours	Date	No.	Hours

Finishing Time.

12	½	1	½	2	½	3	½	4	½	5	½	6
6	½	7	½	8	½	9	½	10	½	11	½	12

NOTE: —Starting and finishing times punched in the squares provided to the nearest quarter of an hour, the shape of Punch indicating a.m. or p.m.

APPENDIX E.

COMPARISON OF PIECE-WORK AND PREMIUM COSTS.

Piece-Work Price	Premium Cost	Premium Balance Paid %	Piece-Work Price	Premium Cost	Premium Balance Paid %	Piece-Work Price	Premium Cost	Premium Balance Paid %
Each	Each		Each	Each		Each	Each	
19/-	10/2	20·9	8/-	7/7	18·1	45/-	33/10	21·6
7/4	3/10	20·9	20/-	15/10	21·6	1/1	-/9½	28·1
8/6	4/9	29·0	2/11	1/9	18·8	-/10	-/8	
1/2	-/6	27·2	25/-	17/3	17·9	-/2	-/1¼	39·0
-/10	-/3½		25/-	18/-	16·5	-/3	-/1	
-/6	-/5	23·1	26/-	25/7	30·7	25/-	17/9	30·4
-/6	-/6		12/-	8/9	20·3	4/6	3/9	35·2
-/8	-/4½		16/-	13/8	22·8	25/-	17/-	33·0
-/8	-/6	20·0	11/6	10/7	23·1	1/1	-/8	30·1
32/-	13/7	18·0	12/-	8/9	19·0	25/-	16/8	25·6
24/-	16/4	14·0	13/-	10/9	25·8	1/4	1/-	20·4
25/-	16/9	14·0	4/10	2/9	20·8	-/5	-/4	26·0
13/-	7/7	28·3	4/-	3/11		-/8	-/6	
7/6	4/11	23·5	4/11	4/4	19·8	-/8	-/6¾	
4/9	3/6	23·0	5/-	3/3	25·0	26/-	16/6	31·1
32/-	16/-	9·7	7/8	5/6	23·2	-/10	-/7	31·5
1/6	1/2	43·7	1/5	1/-	16·1	-/4	-/3	31·5
1/5	-/11	26·4	3/-	1/3	28·5	14/-	6/10	26·0
1/3	1/1½	24·0	3/11	3/5	24·2	2/-	1/8	
25/-	16/2	29·3	4/-	3/-	6·8	5/6	3/-	34·0
2/-	-/9	13·4	4/-	3/7	12·4	2/4	1/6	33·2
1/8	1/-		7/8	5/3		26/-	22/9	25·0
3/-	1/3		-/8	-/6	14·2	3/-	-/9	30·1
15/9	13/1	23·8	6/4	3/10	19·1	4/3	3/7	20·0
			4/8	4/-				

DISCUSSION.

Mr. G. SAXON (who took the chair owing to absence of Mr. E. G. Constantine, through illness), thought they would all agree with him that Mr. Ashford had provided them with some valuable information by introducing this subject of the "Premium System." These systems of remuneration were of great interest to the Engineering Trades, and as the premium system was one of the latest methods, it seemed likely judging from the paper, to prove the most effective way of dealing with the payment of labour.

Mr. H. F. MASSEY thought some credit was given to the "Premium System" which really did not belong to it, and that some of the advantages claimed were really due to having a good system of remuneration, and adhering to it, rather than a bad one, as a good and carefully watched "piecework" system was certainly much better than one carelessly watched, and this ought to be taken into account.

He was of opinion that Mr. Ashford had not overrated the advantages of the "premium system." From experience however, he believed that the "Rowan" system had more advantages than the "Halsey" system, as his firm had tried both and had found the former to be the better one.

He observed that no reference was made in the paper to the premium system having been applied to fitters, or others who must often work in groups instead of singly. He however, did not think that it was impossible to make it applicable to them also.

Speaking of two machine work, he did not think that the method advocated by the author was the best, as it did not offer enough inducement to the worker. In the Rowan system used by his firm one man working two machines received the full premium from each machine, and anything less than this, in his opinion, did not call forth the men's efforts to make the system a success.

As regards the starting of a premium system in a works, it appeared to him that the remarks in the paper were hardly correct, as it was possible to commence the system gradually and with less detail, without going through such elaboration as stated; but of course it was necessary to be careful and to thoroughly consider the matter before adopting it.

The analysis of work done, as shown in the paper, was admirable. In his opinion, however, the chief advantage was

not so much in getting at an accurate price, as in showing up points in which time might be saved was more outside the workmen's control.

The system necessitated thoroughly competent foremen who had completely mastered it beforehand, otherwise he would certainly adopt a simpler one.

Mr. W. A. TRITTON said that his firm had about 1,400 men working under the premium system; the "Weir" or "50 %" being the particular system that had been adopted. It is interesting to note that the "Weir" method was favoured by the manager, who had had a large experience of the "Rowan" system at Elswick. The chief advantages of the "Weir" system being:—

(*a*). That the men understand the "half-and-half" payment more readily than the varying percentage.

(*b*). That the pecuniary advantage derived by a man increases at an increasing rate, in proportion to the time saved. His firm did not carry forward any debts made by the machine hands, but found it advisable to do so as far as the fitters were concerned.

The introduction of the premium system has necessitated an extension of the limit gauge system, and an inspection staff, independent of the foremen.

It was found that the men would not take the trouble to make out their job notes with sufficient care to enable the premiums to be correctly calculated, nor, indeed, to enable the prime cost department to establish any reliable records. Shop clerks were therefore started to do this work, one man booking the work for about 60 machines.

The question of debts was very important, because the fact of a man making a debt showed that there was something wrong. These debts at present averaged 225 hours per week; if they

could be abolished it meant a direct saving of approximately £8 per week, and an indirect saving due to quicker output, etc. The individual debts were carefully enquired into each week. The chief causes were:—Slack belts, looking for drawings, hard metal, unhandy jig, and, most frequent of all, work going through operations in small quantities.

These reasons for excessive cost will obtain more or less in all shops, but the premium system will expose them more readily than any other method of payment for labour.

His firm had never reduced the time on a job on account of a large premium being made; if good faith be not kept with the men, the whole system will be a failure.

Provided that the premium system be carefully introduced on sound methods, and that the men are not scared by any job being "cut" then the happiest results may be expected by its adoption.

Mr. J. Vose observed that it was a topic of very great importance, and the more cautiously any change in remuneration was made the better. He thought the premium system made an opening for the benefit of the workmen as well as for the engineering trades, and that it was a very good precaution which the trades unions took when they said that a man must have either the premium system or none at all.

In the cotton trade the employers and trade union representatives could meet as experts on any subject appertaining to their sphere, and as equals, which was the thing required in the engineering industry. A short time ago the cotton manufacturers demanded a 5% reduction in the wages of their workmen owing to bad trade. When the men's representatives met the employers they agreed that trade was bad, but said that although they were not very much opposed to the reduction *per se*, they did not see that the employers would gain any advantage because the gain would only go to the merchants. This he

thought was the idea which Mr. Halsey had anticipated when introducing his system, and instead of paying the man the full two hours saved, he gave the workman so much premium, so that eventually he would not have to take it from him again.

He remarked that a good deal could be said for the Manchester system of piecework, *i.e.*, that standard wages must at least be paid, but where a just remuneration is offered by the masters, the difficulty was to get just men to work these systems. It would never do if the masters and the men were always on the *qui vive* as to who would get the advantage.

Mr. S. N. Braysbaw said that he remembered when he was an apprentice they were put on a system by which they were paid time and a quarter and nothing more, although if they had been paid for all the work and time they could have saved, he could not say how much money they would have made.

He thought that if it paid a master to give a shilling on the piecework system, and it took the man an hour to do it, it would certainly pay him as well to give a shilling for the same job if it only took a minute, because the saving was in the standing charges.

In his opinion the vital point which made this system valuable was that the saving in wages was divided between the masters and the men, whereas on the piecework system the wages cost remained constant for the master. The fact of cutting down the prices destroys at once the harmony which should exist between the parties concerned.

He thought it was a very interesting paper, and the subject was one deserving to be brought before their Association. The whole tone of the paper was excellent, and the way in which the questions were considered from the master's and the workman's point of view was admirable, because, if they wanted to get the most out of the man, they should give him every possible encouragement.

Mr. A. Hobbs asked whether the author could give him any information as to how the foreman shared on this system, since there would be a great deal more work put upon him.

Mr. J. Nasmith said that the fact of it being a bargain made between the two parties concerned seemed to him the most valuable part of the paper, but he failed to see why a properly propounded piecework system should not work equally as well as the "premium system."

It appeared to him that there was an assumption borne out in the paper and illustrated in the Table E, which was that in stating the price of a job, a correct basis was found when working on the premium, whilst on the piecework system a false basis was assumed. He took it that to commence a man on either of these systems would necessitate the same careful observations as to what work could be turned out, and the limit of time taken by a machine.

In his opinion, there was an undisclosed fact lying at the bottom of these arguments, which was, that in the past, people who had fixed piecework prices had looked at one side of the question only, and when they found a man earning more than a certain sum they at once began to cut down the prices, which caused so much dissatisfaction

In the premium system however, when once a price is fixed, it will have to remain unaltered until the employer finds the man more efficient machinery to help him to get the work done better or quicker.

His advice was that if anyone was contemplating the commencement of either the premium or the piecework systems, they must make a bargain, and adhere to the prices given.

There was also a wrong idea in this country that wages was a matter of great importance, whereas the most important thing was the cost of the finished article, and this was the point that

really required the attention of employers in all ranks and industries of this country, and not the question of how much wage a man should have.

The best method of making any system a success was to get as much as possible out of every square yard of floor space they had, and the way to do it was to increase the speed of the machines. If they could do it the idea was to intensify the production.

An American friend of his once remarked that his aim was to get as many dollars from every foot of space that it was possible to do, and he did not care whether the workman received 20, 40, 50 or 100 dollars per week so long as he got more out of it, and that once he had made a bargain he never went beyond it. That was the spirit required in this country.

He would like to ask the author what he would do where, as in some cases, they got a certain class of men who, however much premium they were prepared to give them, would not earn more than a certain number of pence per hour. What was he going to do with the premium system in a case like that? When workmen got into this state it appeared to him that any such method of payment would be hopeless. He was certain that this spirit of the workmen to only earn so much per hour had originated from the persistent breaking of bargains between the employers and employees where the piecework system had been adopted. There were two sides to this question, and both demanded equal recognition, otherwise if the employers again did not carry out their obligations, they would be unable to make any system of remuneration a success.

He thought that the author had very clearly shown the conditions in regard to the premium system, and deserved the warmest thanks of the Association for the intelligible and popular manner in which he had presented this subject, still he could not find anything mentioned as to what the carrying of this system

into effect would be. It meant a certain amount of clerical work, and the office staff in some of the American factories were nearly as numerous as the workmen, and there were clerks booking this and booking that on account of these systems. In his opinion, there seemed to be a tendency in many places to get as many clerks as possible, which appeared to do away with economy. In one workshop, which he had visited in America, and which he was rather surprised to find in that country, the men had only to write the particulars of the job on a board, but there was no elaborate card system, and the work seemed to go off first rate.

He did not like the word "oncost" mentioned in the paper, possibly it was an "Americanism," but it certainly was not an elegant word, as it did not convey a proper definition. He would suggest that the word "shop charges" might be better applied in this case.

The CHAIRMAN (Mr. G. Saxon), remarked that the thanks of the members were due to Mr. Ashford for his admirable paper, and for the time and trouble he had given to it. He had pleasure in moving a vote of thanks to Mr. Ashford, which was unanimously adopted by the members.

Mr. ASHFORD in replying to the discussion, thanked them for the way they had received the paper, and said he would first make a kind of general response.

As regards the difference between piece-work and premium systems, the reason in his opinion, where the latter had the advantage was, that there was no need or necessity to cut down prices as in the former. When an employer considers that a man has earned too much money when working on piece-work, and that he was getting no direct reduction in the cost of his goods, the price was at once cut down. Not so in the case of premium, for whilst the man would be getting an increased percentage, the actual cost to the employer *would go down;* there-

fore, it became possible for the master to say that the time given should be standard, and should not on any account be cut down.

Mr. Massey had stated that it was not necessary to make an elaborate start with this premium system, with which opinion he agreed; and, although there were certain sentences in the paper respecting this, they did not necessarily imply that an elaborate start was necessary. They were put in the paper in order to indicate to the uninitiated how to act in commencing the system. He was however, rather inclined to question the idea of running piece-work and premium parallel in any works, and thought it would be better to stop piece-work if any master intended to start with premium to avoid comparisons and complications.

The system could certainly be applied to fitters in addition to machinists, although the most gain would be got from the latter, The fitters would get through their work smartly if put on premium, but he would advise anyone to be certain that there was full work to keep this class occupied, so that there would be no cause for complaint, before experimenting with them. Naturally more mention had been made of machine work, because it was with this class that he (the author) had been more connected.

Speaking of the difference between the "Halsey" and the "Rowan" systems, he thought that the chief point in favour of the latter was that when there was a high saving of time, the percentage did not become too heavy with the work, whereas with the other system the percentage became higher. Thus, whilst the percentage may become higher than 100 in the "Halsey" system it could not exceed 100% in the "Rowan." The man would therefore get a greater proportional return for his efforts in the latter when about 25% to 40% had been reached, but beyond that it became less than at the commencement.

As regards the importance of debts mentioned by Mr. Tritton who had assumed that because little had been stated in the paper

about these debts, they were not considered particular items. These were very important indeed, but it was really a question of management, and they should naturally be followed up to trace the cause of them, in order, if possible, to put things right.

Referring to the Diagrams which Mr. Tritton remarked upon, he said that not every one could afford to dispense with old machines like his firm had done, and therefore it was necessary to have a record of the times taken by different machines to do a job.

Mr. Tritton had mentioned a strong point in the necessity for getting hold of the goodwill of the workmen, with which he was entirely in agreement, and thought he had placed full stress upon this point in the paper. It was absolutely necessary to be fair and just in all dealings with the workman, and to let him see that no shabby tricks would be served upon him.

He did not quite agree with Mr. Vose regarding the Manchester piecework system, as in setting a time for piecework they had practically to get the extreme nett time, whereas in premium it was not so necessary to have such a rigid rule. Moreover the Manchester method did not do away with the idea of cutting the prices, which was the greatest objection.

Mr. Brayshaw had brought up a strong point against piecework when he spoke about the juggling of time that goes on in order not to get more than time and a quarter, and he quite agreed with him in that it is frequently done to a serious extent. There was also the advantage of commencing on a clean slate with the premium as mentioned by Mr. Brayshaw.

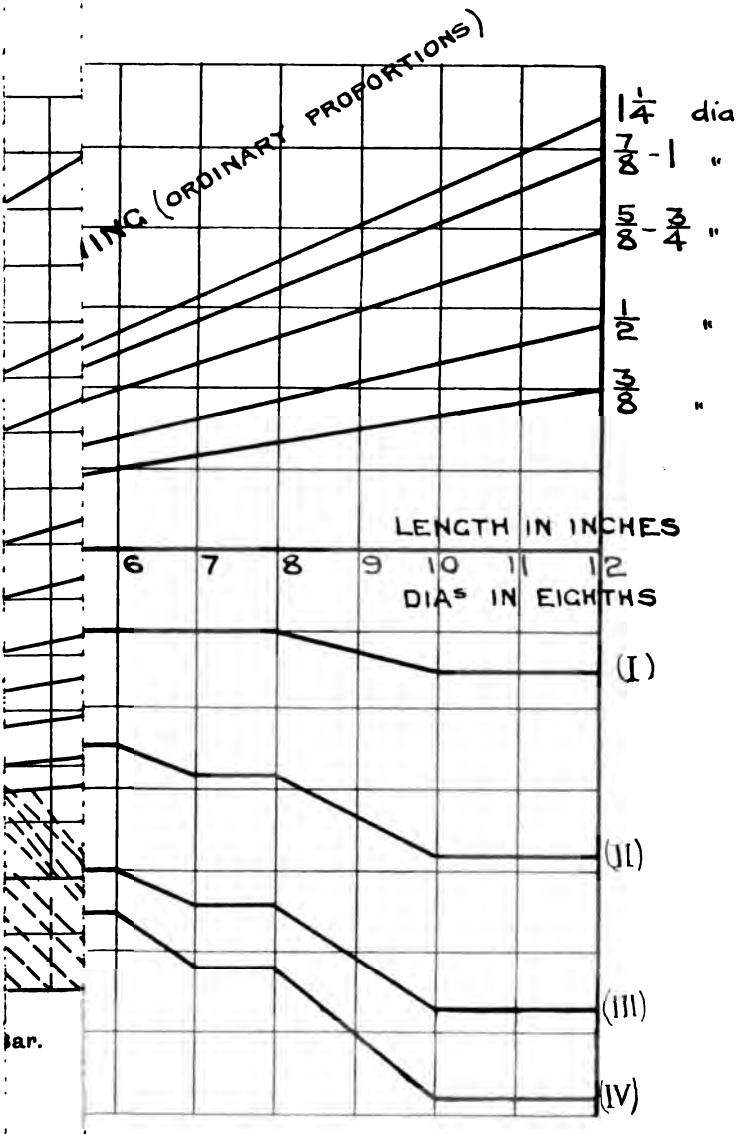
He certainly was of the same opinion as Mr. Nasmith that the chief thing to consider was the cost of the article and not the wage of the men. If the masters can give the men good wages and get a low cost for the articles, it would certainly be satisfactory for all parties, and this is practically accomplished by the premium system of remuneration.

3 Plates follow illustrating this Paper.

R.

IAGRAM 3.

Bar, "Herbert" or "J. & L. Lathe."



Bar.

ing the finished diameters of bolts. Then add time of subsequent operations read

UNIV OF ILL

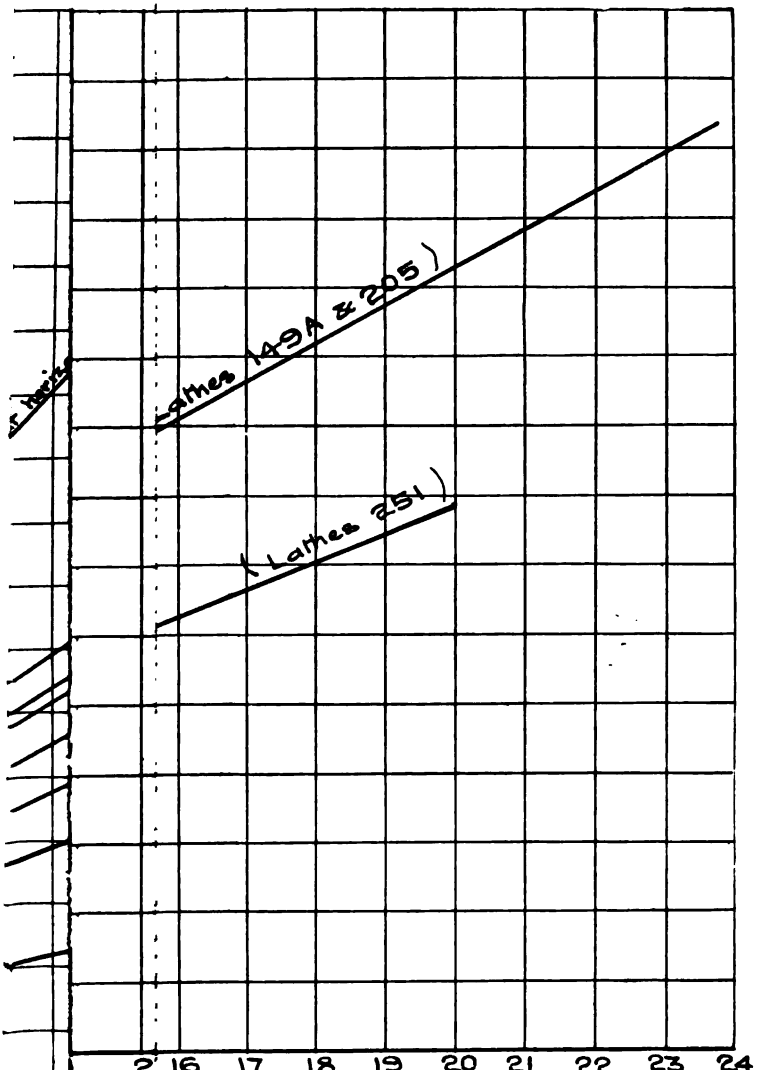

Lathes 149A & 205
Lathes 251
2
16
17
18
19
20
21
22
23
24

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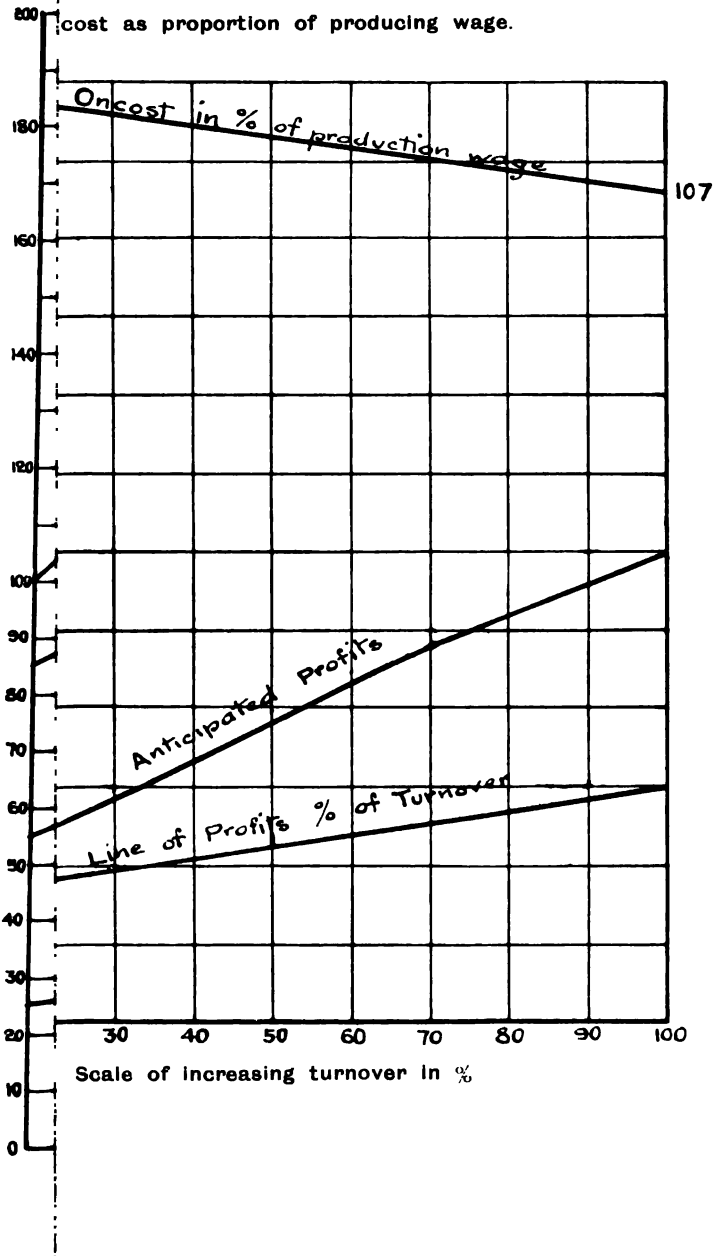
DIAGRAM 8.

icipated Profit with increased turnover.
cost as proportion of producing wage.



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THE EQUIPMENT OF THE MECHANICAL ENGINEERING LABORATORY OF THE MANCHESTER MUNICIPAL SCHOOL OF TECHNOLOGY.

READ SATURDAY, 25TH APRIL, 1903,

BY

JOHN T. NICOLSON, D.Sc., M.Inst.C.E.

(MANCHESTER.)

In the course of a tour of inspection of the American and Canadian Technical Colleges and Engineering Schools in 1897, made by Mr. (now Principal) J. H. Reynolds, as Director of Technical Instruction of the City of Manchester, the author's laboratories at McGill University, Montreal, were visited, and the question of the type of an experimental engine for the new Technical School, then in course of erection in Manchester, came under discussion.

An arrangement was subsequently made whereby designs for this engine were prepared under the supervision of the author, when in Britain during the summer of 1898; and this finally led to his being offered an appointment by the Manchester Technical Instruction Committee to take charge of the equipment of the Engineering Department of the new School.

As this equipment gave promise of being upon a scale never before attempted in Europe, it was with much satisfaction that the author undertook the work and was able to make a serious commencement *in situ* in June, 1899.

With unexampled foresight the Committee arranged that the author's whole time should be devoted to this task, and no

lecturing or other teaching work was expected from him whilst the design and installation of the laboratory equipment was in progress. A staff of four draughtsmen was placed at his disposal for the carrying out of the work intrusted to him, and it is but seldom that such an opportunity has been afforded for the provision of the best possible experimental plant. In the author's view, the thanks of the engineering profession are due to the Committee and Director of Technical Instruction of this City for the courage and enterprise which they have displayed in taking up and carrying through the equipment of these laboratories, on a scale and with a completeness which is certainly without parallel on this side of the Atlantic at the present time.

It is of the first importance, in order to form an opinion as to the appropriateness of the experimental engineering plant installed in the School of Technology to the position it should occupy, and to the needs it is required to supply, that there should be a clear understanding of the guiding principles which underlay the scheme of equipment submitted by the author, and sanctioned by the Technical Instruction Committee.

These principles, as enunciated in correspondence with the Director of Technical Instruction in 1899, were as follows:—

The laboratory of a high school of engineering should serve the following purposes in the education of the young engineer:—

(1) It must help him to understand the principles of the experimental sciences by the use of apparatus embodying those principles in an objective manner.

(2) It must enable him to learn the experimental data, and to absorb the fundamental facts, of those sciences by means of machines for testing the properties of the materials used in the mechanical arts, and of instruments for observing and measuring the fundamental physical

quantities, such as time, mass, weight, length, speed, temperature, pressure, and the like.

(3) It must instruct the more advanced student in the art of proving or testing the more usual types of structures, and the commoner varieties of machines; whether for generating, for transmitting, or for absorbing power, and

(4) It must include within its scope the provision of facilities for experimental work by the actual leaders of industry themselves—or by trained deputies appointed by them—on the problems of engineering design which present themselves in their daily practice. In such a laboratory, it should be possible for standards of perfection to be instituted to which the specimens of any type and class of machine or instrument may be referred; and for a trained staff to be engaged in the constant endeavour to improve the design, both in principle and in detail, of the products of industrial engineering.

The Author is not prepared to maintain that, in the laboratory equipment described in the following pages, the high ideal above set forth has been entirely realised; but at all events an earnest attempt has been made to carry into effect the more prominent of the proposals enunciated, in a concrete form.

For the accommodation of the mechanical engineering department, a large proportion of the basement floor of the School was made available. An area of 17,280 square feet, out of a total basement area of 53,300 square feet, contained in six separate rooms or halls, was allotted for laboratory purposes. A further space of 3,000 square feet, being reserved for steam boilers, electricity station, and ventilation plant.

The general basement plan, Plate A, shows the disposition of the whole.

(1) STEAM ENGINE LABORATORY.

This laboratory is situated next to the electricity station and boiler room, so as to be conveniently supplied with steam either saturated or superheated; and has a floor area 60ft. by 37ft., or 2,220 square feet. A sub-floor gives a further area of 900 square feet.

The general arrangement, Plate I., shows that the principal object, as to size and interest, in the room is a compound horizontal steam engine, driving against a water-cooled band brake on its flywheel, and built entirely for experimental purposes.

(a) Experimental Steam Engine.

It is a surprising fact, when one thinks of it, that the very best steam engines waste 85 % of the coal they feed upon; notwithstanding the unceasing efforts spent by our predecessors and ourselves for more than 130 years in the endeavour to improve them. It is no doubt well known to you that by the laws of thermodynamics it can be proved that no amount of human ingenuity will ever make a steam engine to waste less than about 40 % of the fuel it burns. The physical conditions of this planet have this for their necessary consequence; but there is a large margin available for improvement between these two limits, and our efforts must be unceasingly directed to reducing this margin, and to husbanding the natural sources of energy still left to us, which have been, and are still being, so wastefully employed. The broad principles which govern the direction of the improvement of the steam engine are fairly well understood, as shown by the general adoption of higher steam pressures, and the reversion to the use of superheating which is now taking place; but the writer takes leave to remark that a more particular experimental study of the behaviour of the steam in the engine cylinder has shown that a hitherto but little suspected source of loss plays a more important part than has commonly been supposed.

He refers to the leakage which takes place, past the admission and exhaust valves, of steam which either never enters the cylinder at all, or, if it does so, passes through without doing any work. Since the years 1895-96, when certain experiments on cylinder condensation were carried out by Professor H. L. Callendar, and the writer, at M'Gill University, Montreal, a new method of determining the leakage of valves has been instituted, which appears capable of giving results more closely approximating to those actually occurring than those formerly employed —if, indeed, any method can be said to have been employed at all. The results of many such experiments made upon engines of from 50 to 3,500 HP, have shown that the loss so occasioned may amount to the equivalent of as much as one whole pound of coal per indicated HP per hour; and that the usual loss attributable to this source is probably seldom less than 10% of the whole consumption.

If this defect could be obviated, a notable step would be taken towards the elimination of the above mentioned difference between the efficiency now ordinarily attained and that which is theoretically possible.

The systematic study of the phenomena and laws of this leakage, and consequently of the means to be adopted for its cure, would form a most proper, and in the author's opinion, a most profitable subject to be taken up in workshop laboratories set up by our large steam-engine builders; but so far as the author's knowledge extends, almost no efforts have been made in this direction, it being almost universally assumed that if a valve is tight when at rest, that it may be assumed to be practically tight when in operation. As an exception, the firm of Willans & Robinson may be mentioned; Captain Sankey of that firm having kindly given the author some data obtained by him from a series of experiments on the leakage of piston valves.

The 200 HP engine in this laboratory has been built for the express purpose of studying the questions of the amount and character of the leakage of steam in the case of valves of various types. The engine is of the horizontal compound side by side type, having cylinders 11½in. and 20in. diameter, with 3ft. stroke. It is provided with two cylinders of each size, either of which may be used as desired. One of the 20in. cylinders has slide valves with Meyer expansion plates, and the other has Corliss valves and gear. Of the two 11½in. cylinders one was made by Gebrüder Sulzer, and fitted with their design of drop valves, and the other has Corliss valves and gear of the same type as for the 20in. Corliss cylinder. Thus a comparative study may be made of the efficiency of different types of valves, *e.g.*, Sulzer versus Corliss or Corliss versus slide valves, and of the effect of size-variation by experiments on the 11½in. and 20in. Corliss cylinders.

The pressure may be anything up to 150lbs. per square inch, and the speed up to 110 revolutions per minute. Each end of each cylinder has separate exhaust pipes, so that the amount of steam taken by them respectively can be found by measurement after condensation in separate surface condensers.

The ends, sides and pistons of the cylinders are steam jacketed. The steam, when supplied to any of the cylinders, may alternatively go directly into the steam chests, or may be passed through the jackets before entering them. In the latter case it may or may not pass through a water separator. Steam may alternatively be supplied to the jackets directly from the main steam pipe. The total horse-power indicated may reach 350.

The special feature of the engine, as already indicated, is its adaptation for testing the rate of leakage of steam past the admission and exhaust valves. For this purpose in the Corliss cylinder, each valve casing is a separate casting bolted to the cylinder with an intermediate thin plate *a*, Fig. 1, which may

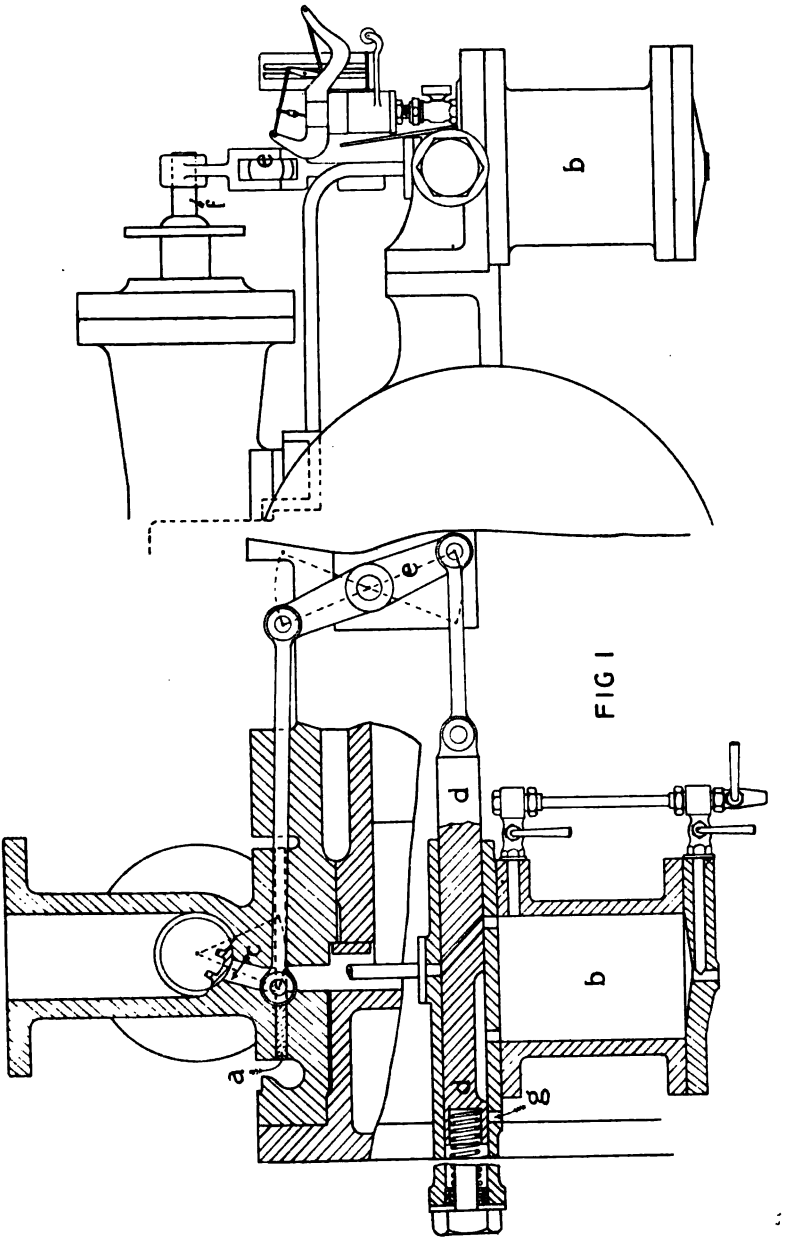

FIG I

either have an opening through it corresponding to the port area, or may be blank so as to shut off the cylinder from the steam chest. Thus when the valves are operated (from the other engine by the crank shaft) under steam pressure, the amount of steam which leaks past the valve when it is closed can be measured by attaching vessels *b*, for catching the leaking steam, to the valve casing, and connecting them to the space *c* between the valve and the blank plate, with the interposition in the connection of a long plug valve *d*, operated by levers *e* from the Corliss valve spindle itself *f*. By preliminarily admitting steam to the vessels *b*, and then throttling or opening their exhaust pipes *g*, the conditions of pressure on the two sides of the main valve may be made to approximate to those occuring during actual running, and indicator cards may be taken from the vessels to show the rate of variation of pressure in them, due to leakage, while the valves are in motion. Allowance can also be made for the condensation taking place in the vessels by taking the temperature of their walls and finding the condensation area from these and the cards.

In the case of the slide-valve cylinder, a thin plate *a*, Fig. 2, is also interposed between the back of the valve-chest face and the cylinder port facings, so that the same experiment can be made with this as with the admission valves of the Corliss cylinders. Recesses have been provided in the back of the valve-chest *b* in which coils of small piping *c* are placed, so that when desired the valve faces may be heated by circulating steam, or cooled by circulating cold water therein. By this means and by the insertion of thermometers within its substance the valve face may be brought to the same state as to temperature as when working normally.

In the case of the Sulzer cylinder, the leak may be studied by cutting off a portion of the cylinder close to each end, from which cards may be taken when the valves are being operated under pressure.

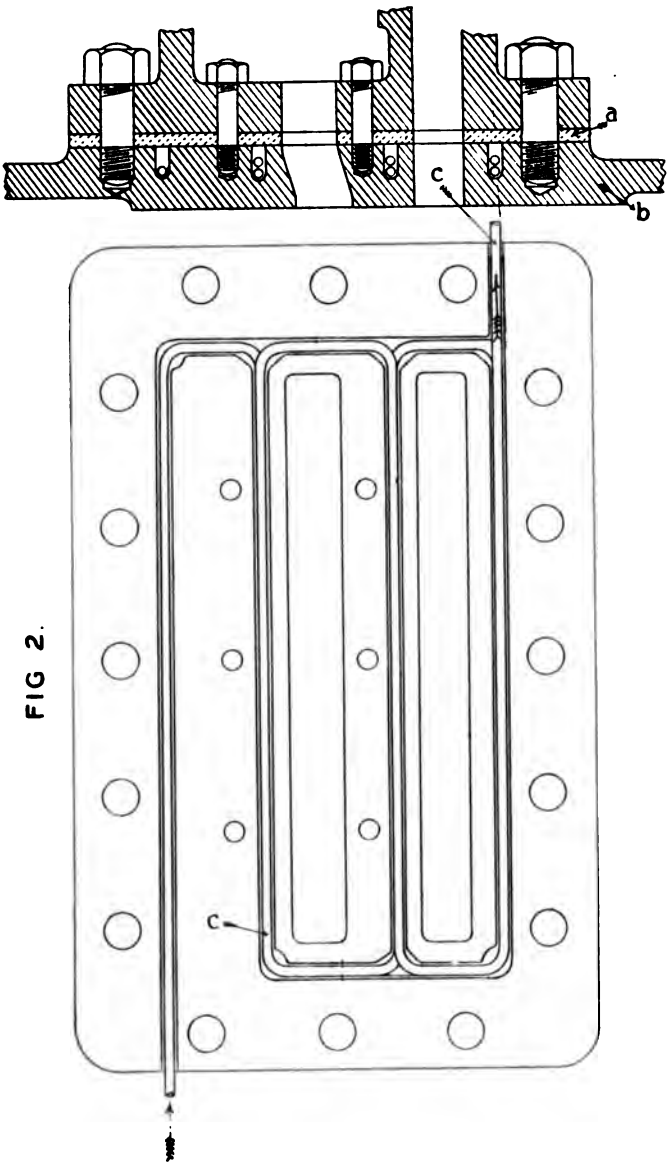

FIG 2.

In all the four cylinders, duplicate exhaust valves of the drop-pattern are fitted at each end, Fig. 3. These auxiliary valves *a* are driven by special gear *b* from the valve motion, and are arranged to open and close simultaneously with the main exhaust

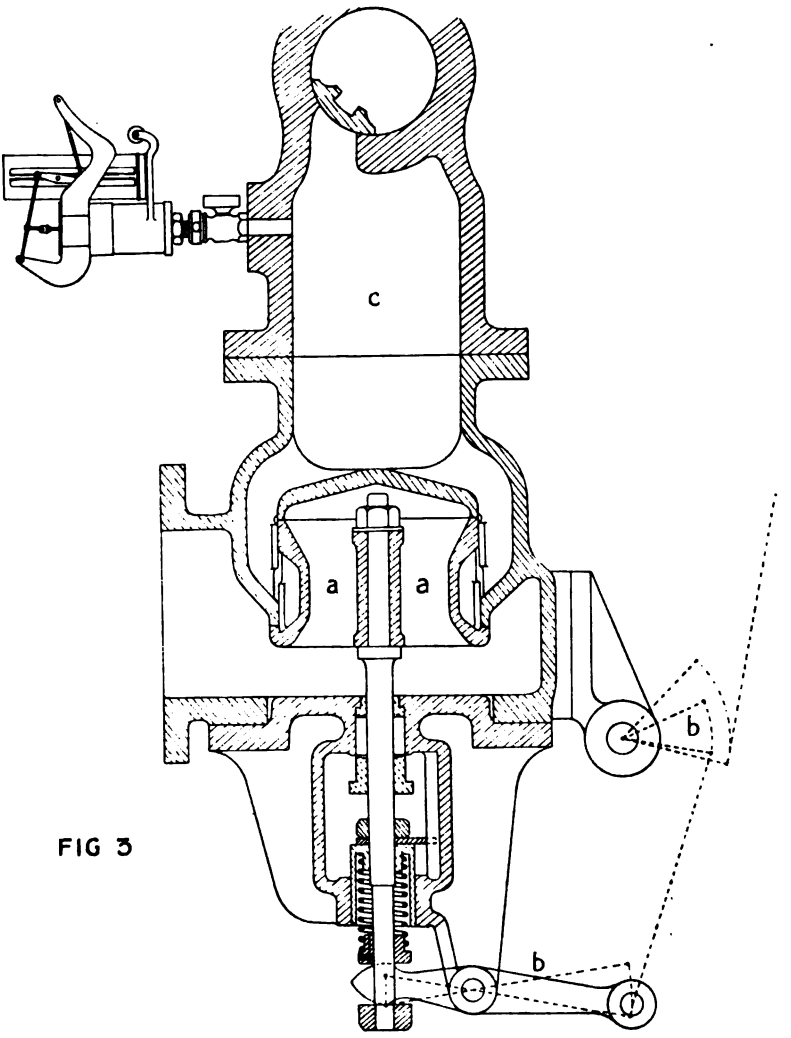

FIG 3

valves, whether of the Corliss, Slide-valve, or Sulzer pattern. By then taking indicator cards from the spaces *c* between the main and auxiliary exhaust valves (and by determining the rate of leakage past the auxiliary valves by special experiments), the leakage past the main valves during actual work can be inferred.

A very desirable addition to the engine would be a cylinder (say 11½in. diameter and 3ft. stroke) fitted with piston valves so arranged that their rate of steam and water leakage might be studied. When the work already before the mechanical engineering department, in connection with the plant already provided, has been to some extent attended to; such an addition will no doubt be seen to be justifiable and desirable.

The engine has two surface condensers of differing types; two air pumps of high speed and slow speed designs, and a great number of pieces of accessory apparatus for experimental work.

It has been admitted by many competent judges that this engine is a most handsome and creditable production, and one showing that no pains have been spared by Messrs. James Carmichael & Co., the contracting firm, to complete the work to the full satisfaction of the Technical Instruction Committee, and their engineer.

In the boiler room there is installed, in addition to the electricity supply and heating service plant, a 500 HP steam boiler of the torpedo boat type, J. W. Reed's patent, made by the Palmer's Shipbuilding and Iron Company, Jarrow. It works at 250lbs. pressure, and serves not only as a reserve boiler for service, but for steam supply to the experimental engines.

A superheater of 400 square feet area, Schmidt's patent, manufactured by Messrs. Easton & Co., Erith, is provided for supplying steam of any required degree of superheat to the laboratory.

(b) Automatic Cut-off Simple High Speed Engine.

An automatic cut-off steam engine of 50 HP, by Messrs. The Ball & Wood Engine Co., of Jersey City, U.S.A., is also installed in the steam engine laboratory, and serves for the preliminary drilling of students in the methods of carrying out the details of engine testing. It is fitted with a number of accessories for experimental purposes; including a special indicator reducing gear for high speeds, and a rope brake on the flywheel for absorbing the power. A convenient arrangement of hand-wheel and screw on the slack side of the rope, in conjunction with a Horn's Tachograph, enables an observer to regulate the speed with great nicety and maintain it at any fixed rate, during a test.

The valve faces and the cylinder walls are drilled in several places for the insertion of small mercury thermometers, of the pattern used by the late Mr. Bryan Donkin; and Mr. Mellanby, who has charge of this department has, during the present session, made elaborate temperature readings in the course of carrying out a number of tests with this engine. This is to constitute a contribution to our knowledge of the way in which the missing quantity is accounted for by cylinder condensation and valve leakage respectively. An interesting piece of apparatus has been fitted in the exhaust pipe of this engine for the direct determination of the amount of wetness of the exhausting steam. The whole of the discharged steam from the engine is dried by causing it to flow over a coil of iron wire heated by the passage of an electric current; and by measuring the quantity of electric energy required to just superheat the steam, the weight of water it contained before passing over the coil can be ascertained.

The state of exhaust steam, as to dryness, when it leaves the cylinder of an engine has always been a moot point amongst steam engine theorists, and the author is not aware that the

above method of working has ever been resorted to for the elucidation of this important question.

Mr. Mellanby's experiments with this apparatus tend to show that the exhaust steam from a simple expansion engine is much drier than might be expected, a fact which goes to confirm the idea that a considerable proportion of high pressure steam has leaked across the valve faces directly from steam chest to exhaust passages.

(c) Air Compressor.

It is generally supposed that the transmission and distribution of energy by the agency of compressed air is of necessity an extremely wasteful process; and the idea of its ever being able to compete with electricity in this respect has hardly entered anyone's mind. The practical success of the pneumatic system of distribution in the City of Paris, where 13,000 horse power are now at work, may be considered to have dispelled this notion. The system there adopted consists essentially of four parts; the air compressor, the air main, the preheater, and the motor. The improvements effected in the mode of compression and in the use of preheated air in the engines have rendered it possible to obtain just as much work at the motor as was supplied at the distant compressors;—to obtain, that is, a practical working efficiency of transmission of 100 per cent. This is secured by means of a very insignificent expenditure of coke as fuel in the small stove or preheater through which the air passes to the engines. The pneumatic system of power transmission is the only one in which it is possible to insert energy at the working point sufficient to make up for all losses in transmission, without any sacrifice of practical convenience and at an almost insensible cost.

The air motors and preheaters in Paris are attended to—or rather left unattended—by waiters and domestic servants who have all manner of other duties to perform. All they have to do

is to turn on the stop-valve, refill the lubricators, and put on a shovelful of coke once or twice a day. As Professor Riedler (who made an exhaustive report on the Paris system) remarks, "the air motor appears to be an even more long suffering machine than the steam engine, which is justly renowned in this respect." If the preheater be turned off, the exhausting air may be used for refrigeration. Thus, large confectioners in Paris use their air motors during the day for driving mixing and cutting machines; in the evening, they drive their dynamos for lighting, and the exhaust is used for making ice. In summer time, the exhausting of the clean cold air into the workshops is a very great advantage.

It would be easy to enlarge on the many advantages of this system of distribution of power; but enough has perhaps been said to show the importance of having an experimental air compressor of the latest type exemplified in the equipment of the engineering laboratories of this School.

In compressing air it is of the greatest importance to keep it cool if a high efficiency of the process is desired. If the air could be compressed quite slowly so that the work done upon it by the compressing piston, which is changed into heat (or vibration energy in the particles), had time to pass away into the walls, the compression would take place at the temperature of the entering air (*i.e.*, isothermally) and a notable reduction in the work required to raise the pressure by the desired amount would be effected over what has to be spent if the heat is allowed to accumulate in the air. If, on the other hand, the compressed air is to be used in motors close to the compressor, no great harm is done. When the compressing is done so quickly that the temperature of the air rises in the cylinder, then the extra work put in is returned again in the motors. But if the heated air has to travel through a long main before being used, its temperature has time to fall to that of the ground, and all the extra

work necessarily accompanying high temperature compression is thrown away. For transmission purposes, therefore, the most economical way of compressing the air is the isothermal method; and this has long been acted upon in practice by the use of cooling jackets round the cylinder and even in the pistons, as the slow compression process above mentioned would be impracticable, owing to the great first cost of the large-sized machines which would be necessary. For the purposes of a large first class compressing station, however, this jacket-cooling is far from being the best possible system, and is only to be recommended for mining plants where the injection of a spray of cold water into the cylinder itself is impossible, owing to its impurity or to the undesirability of any additional mechanism. Even with the best forms of spray injection now in use, only a relatively small proportion of the heating can be prevented. Instead of remaining at the temperature of entry, say 60° F., the air, when being compressed to a 100lbs. absolute, heats up to about 300° F., as against 455° F., which would be the terminal temperature if no heat had been taken away at all.

A much better method of dealing with the difficulty is to compress in two or more stages. This is accomplished by permitting the air, after its pressure has risen a certain amount, to flow into an immediate receiver of sufficient capacity to allow of the lowering of the temperature of the air down to that of the atmosphere before it is inhaled into the next cylinder. Professor Riedler applied this method on the 10,000 HP installation in Paris with pronounced success. As to the inventor of the plan no certain information is obtainable. The Norwalk Iron Works Co., Conn., constructed compressors on this principle as early as 1881; and Mr. Northcott, of London, made a compound compressor with intercooler as early as 1878.

The compressor constructed for the School of Technology is of this two-stage type for pressures up to 150lbs. per

square inch. The cylinders are 14in. and 7⅛in. diameter, with 12in. stroke; and are placed side by side. They have water jackets for cooling; but are also furnished with spraying nozzles for injecting water into the cylinders themselves. The comparison between 2-stage and single-stage compressions can be carried out by running the large cylinder only, and connecting it direct to the reservoirs. An intercooling receiver is fitted, in which the air, after discharge from the LP cylinder may be cooled by the further injection of spray; the water being removed by a water interceptor before being admitted to the HP compressing cylinder. The general arranagement of the plant is shown on Plate II.

The ultimate form of compressor will no doubt be a reversed turbine. Mr. Parsons has already constructed a turbo-compressor to work up to 40lbs. delivery pressure. Meanwhile, the reciprocating compressor holds the field, and in designing an experimental machine of this type the attempt has been made to arrange it so that different types of suction and discharge valve could be fitted at pleasure and their action studied at various speeds and lifts.

One set of valves was designed for controlled closure after the manner of Professors Riedler and Stumpf, of Berlin. Fig. 4 shows two views of one of their discharge valves. They are ordinary mushroom valves made of forged steel, with a central tube acting as a guide, and a small piston fitted on its rear end. During compression the air gets behind this piston so that a force is brought to bear upon the valve tending to open it, due to the difference of area of the piston and the valve itself. The valve does not open outwards like an ordinary discharge valve; but towards the interior of the cylinder, and in opposition to the air streaming past it when open.

The little valve-piston also retards the valve, when opening, by acting as an air buffer; the action being regulated by a set

screw. The travel of the said piston also limits the amount of valve lift. The valve is closed mechanically by the compressor pistons at the end of its delivery stroke. A light spring fitted in the piston pushes it gently to, no matter at how high a speed the compressor may be running. In the Stumpf compressor the inlet valves were cylindrical rocking valves of the Corliss type.

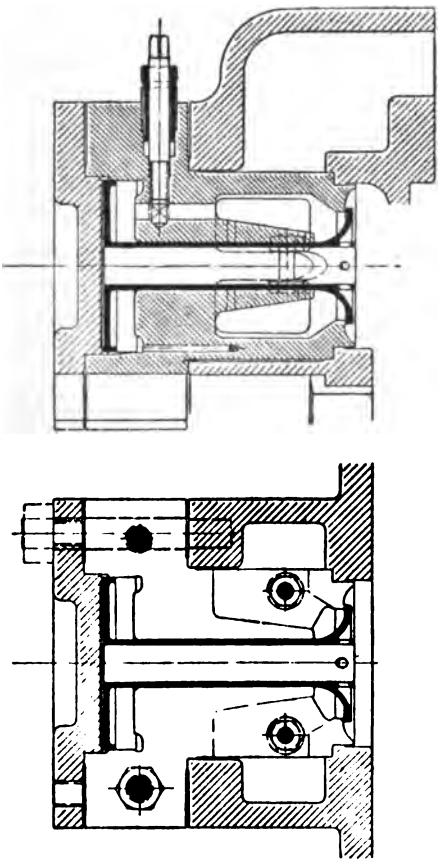

Fig. 4.

STUMPF'S PATENT AIR COMPRESSOR DISCHARGE VALVE.

The designs for the School compressor valves are shown in Plate IV. The discharge valves of Stumpf pattern are shown at C; the pistons being shown fitted for effecting closure. Design A is for a delivery valve opening outwards automatically; but closed by a push-rod operated from the crosshead. Design B shows the same valve modified to close as well as open automatically; a light spring being inserted to ensure the valve being kept on its seat.

The suction valve designs are also of three different types. In A and C they are mechanically closed by levers and push-rods from the crossheads, but open automatically; in B the valves both close and open automatically. In Design A the valve will not begin to open until the pressure in the cylinder is about one pound per square inch less than that of the atmosphere; whereas in Design C owing to the light pistons fitted to the valve (the inner side of which communicates with the compressor cylinder and the outer side with the atmosphere), there would be a force of about 20lbs. operative to open the valve when the pressure difference had reached this amount. All the valves, both suction and delivery, have their spindles prolonged to the outside so that a small rod and pencil attachment may be screwed in, for the purpose of taking indicator diagrams of the valve-lift By this means the operation of the various types may be studied under different conditions of running; as to speed, spring load, buffering, &c.

The general design of the compressor is shown by Plate III. It is driven by a directly connected electric motor; whose speed may be varied between 40 and 300 revolutions per minute by using a water rheostat in the main circuit.

The air delivered by the compressor (at any pressure up to 150lbs. per square inch) may be stored in the three cylindrical reservoirs, after passing through two smaller ones where it is cleared of cooling water. From these it may be led to the gas

and oil engine laboratory, there to be delivered into an air holder from which these engines draw their air.

Alternatively, the compressed air may be turned on to a 50 HP Ball and Wood high speed automatic cut off single cylinder engine for driving purposes. It is the intention, ultimately, to fit a preheater for the air before supplying it to this engine; when the phenomena of this very economical process of transforming heat into work (whereby an additional horse power is obtained for every $\frac{3}{4}$lb. of coke burnt) may be observed and studied.

The compressor was built to designs prepared in the School by Messrs. Steven and Struthers, of Glasgow, and reflects credit upon that firm as a first class piece of work.

For the working out of the design of the valve gear, which required much thought, the author is specially indebted to Mr. P. W. Robson.

(2) THE HYDRAULIC LABORATORY.

(a) General Description.

The equipment of the hydraulic laboratory is fairly complete and on a somewhat extensive scale. The elaboration of this department has by some been objected to on the ground that hydraulic power is not made use of to any great extent in this country, and that, therefore, the practical usefulness of such a department could not be great. It may be replied that whilst it is true that we are far behind continental engineers in experience and skill in hydraulic power utilisation; this is because we have had such an abundance of cheap coal that our water powers have never been exploited. It is certainly not because we do not possess them in abundance. They have not been made available because at present water power is more expensive than steam power. The cost per annum for interest and depreciation upon the capital expenditure for the dam,

head and tail races, penstocks, gates and wheel-pit of a turbine power plant is from 10s. to £3 per horse power according to the nature of the site of the waterfall impounded. On the other hand, the sum of £4 per annum will amply cover the cost of one horse power obtained from the burning of coal by a large steam engine. The difference between these figures, varying between £3 10s. and £1 per HP per annum is what remains available to cover the cost of transforming the power at the water supply into a form suitable for transmission, for its subsequent conveyance to the point where it is to be used, and for its retransformation into mechanical work. The fixed charge and the running expenses of any such transmission has hitherto generally exceeded the above available balance, and the steam engine is found to be the cheaper.

But this condition of affairs cannot long continue, even in this favoured country. The day seems to be almost at hand, owing to the great advances which are being made in the means for the transmission of power, especially by the alternate current at high tension, when it will pay to harness waterfalls 50 or 100 miles distant. As coal becomes scarcer hydraulic power will take a more prominent place; and, if the statisticians are correct in saying that in 50 or 100 years coal will cost as much as iron; and that there will be so many people in England that it will be difficult to supply them all with drinking water, the value of water power may be so great that our grandchildren will only be supplied with the precious fluid after it has been depleted of its energy in the shape of mechanical work by passing through turbines!

This is, of course, a far-fetched argument in support of a present day hydraulic laboratory equipment; but there are other good reasons to be advanced. Water supply and sewage disposal involve many hydraulic problems, and both these questions are of vital and present interest to us. Great success has attended

the distribution of power in our great cities by means of water under high pressure; and this branch of engineering is likely to give employment to many of our young engineers. Hydraulic machinery such as cranes, power-presses, pumps, elevators, &c., occupy a large field in the view of the engineer; and finally the principles of hydraulics, if thoroughly mastered, have a so much more than merely fortuitous analogy to electrical problems, that the study of the one very often facilitates the solutions of the other.

The hydraulic equipment in this School is really much more extensive than the space specifically appropriated as hydraulic laboratory would indicate. In addition to the laboratory itself, which is 39ft. by 24½ft., there is a tank house on the roof, with a floor space of 51¾ft. by 10½ft.; an area of about 20ft. by 20ft. in the steam engine laboratory; and a long trench through the workshops 110ft. long by 5ft. inside; which all contain tanks, channels, pipes and other appliances devoted to the storage, supply or measurement of the water used in the hydraulic laboratory. The arrangement of the whole is shown on Plates V. and VI.

In the first place, the large tank at the top of the School, a composite structure of steel and iron, 46ft. long by 6ft. 6in. wide and 7ft. 6in. deep, is capable of holding 11,000 gallons of water. See Plate VII. It is connected by a 12in. main 338ft. long with the turbines and other appliances in the basement; and by its means a constant head of water up to a maximum of 100ft. can be maintained for the purposes of a test. The design and erection of this tank was not altogether an easy matter. Being situated over the grand staircase, the supports upon which it rests were of necessity 45ft. apart; so that it had to be constructed not merely as a tank but as a girder to support itself. Then again, its great height above the basement and the small door in the

tank-house through which everything had to be passed necessitated its being made in small pieces; and due credit must be given to Messrs. Glenfield and Kennedy, of Kilmarnock, the contractors, who succeeded in making it staunch and stiff under such difficult conditions.

The turbines which this tank supplies are three in number and each of 20-brake horse power. Their arrangement in the laboratory is figured on Plates VIII. and VIIIA.

One is a Girard or impulse turbine with partial admission, radial outward flow and horizontal shaft, Plate IX. The others are reaction turbines of the Thomson or Francis type with horizontal shafts, having radial inward flow and working with draft tubes, Plate X. On their most economical speed, which is that due to a fall of 50ft., these turbines use about 280 cubic ft. or 1,750 gallons of water per minute; but with high heads and slower speeds than the normal, quantities up to 3,000 gallons a minute may be required. At such high rates of consumption of water, the large high level tank could only keep up the supply for about four minutes; and as the turbines must run for a considerable time in order to get the conditions steady enough for a satisfactory test, means had to be devised for keeping the tank replenished from another source than the Corporation mains; from which it would have cost £3 or £4 per hour to work only one of them.

A centrifugal pump was, therefore put in, capable of delivering normally 2,000 gallons per minute against a total head from suction well to tank level of 128ft, see Plate I. To discharge this quantity the pump runs at 950 revs. per minute, and is driven by a continuous rope from a 200 horse power electric motor running at 300 revs. per minute. The pump and motor are, however, capable of being speeded up until the revolutions of the former are 1,200 and then it is capable of delivering 3,000 gallons per minute into the high level tank.

This centrifugal pump, constructed by Messrs. J. & H. Gwynne, is of their twin-series type; the discharge of the first pump delivering into the suction of the second. A similar method of working was invented by Professor Osborne Reynolds; and pumps called Mather-Reynolds pumps have been made on this principle for some time by Messrs. Mather & Platt with three or four, or even more, centrifugal pumps in series, for very high heads. The design of this pump has, I am informed by Mr. Earl of that firm, recently been very much improved by the collaboration of Messrs. Sulzer of Winterthur, and very high efficiencies are now attained.

The electric motor used for driving not only the Gwynne pumps, but alternatively the two-stage air compressor elsewhere described, was manufactured by the Lancashire Dynamo and Motor Co., of Trafford Park, and designed by Mr. A. P. Wood of that firm. By reason of its special construction with a double armature winding and two commutators, which enable these two windings to be put either in series or in parallel, and by the use of a liquid rheostat in series with these conductors, the widely varying conditions of service to which it is subjected have been successfully met.

These conditions include the following:—Not only must the centrifugal pumps be driven at motor speeds of 300 to 500 and horse powers up to 150; but it must be possible to run the air compressor at any speed from 40 revs. per minute up to 200 or 300, with an approximately constant torque, or in other words, at a horse power varying nearly as the speed.

By the use of this electric motor, taking its power from the electricity station in the School, and the centrifugal pumps, a continuous supply of 3,000 gallons of water per minute can be maintained for the purpose of hydraulic experiments; the water after discharge from the turbines, passing over a weir and through measuring tanks to the suction well below the pumps,

and from there being returned by them to the high level tank. The cost of the required power amounts to about £1 per hour at the maximum rate of working.

(b) Water Measurement.

The turbines discharge either freely or through a draft tube into the flume shown on Plates VIII. and VIIIA., and the water is stilled by passing under screens and through perforated plates before reaching the forebay of the sharp edged rectangular weir, by whose means the quantity flowing is estimated. This forebay is 4ft. in width by 7½ deep and 15ft. in length from screens to weir. The weir itself, Plate XV., may be of any width from ½ft. to 4½ft. advancing by ½ft.; and the head of water over the crest of the weir may reach 2½ft. The fine hook gauge used for measuring this head was designed and constructed by the Cambridge Scientific Co., and is shown in Plate XVA.

After falling over the weir the water flows through a kind of lock and a sluice valve (on which submerged weir experiments may be made) into a long trench in the floor of the mechanical workshops, which leads to another forebay opening over the measuring tanks.

These measuring tanks, six in number, Plate XIII., each of a capacity of about 600 gallons are placed in a large excavation in the floor of the steam engine laboratory. As seen in Plate I., they are placed two and two; so that the three square cast-iron pipes leading from the forebay just mentioned are able to serve two tanks each. Each tank is supplied and emptied by means of two 15in. diameter lift valves. These valves are operated from an interlocking arrangement of handles by means of high pressure town's water. The handles open and close small slide valves which admit or exhaust the pressure water from the upper

or lower sides of small pistons working in cylinders formed in the valve boxes and connected to the valves themselves, Plate XIV. It is impossible to admit water from the forebay to any tank so long as the outlet valve on that tank is open. The water is measured volumetrically by allowing it to fill up to, or rather over, the level of the conical overflow pipe in each tank; when the flow is diverted into the next. The waste from the overflow pipes is caught in a separate tank common to all the six large ones, and so accounted for.

In this way it is possible to check the ordinary formula as applied to the weir in the laboratory by actually measuring the water flowing, up to a maximum of about 3,000 gallons per minute.

(c) Vee-Channel.

The long trench between the hydraulic and steam engine laboratories was taken advantage of for the installation of a fine and unique vee-channel made of cast-iron pieces of rectangular vee-shaped section bolted together to a total length of 110ft. The inside of the channel is carefully planed and the ends of each piece are machined square so as to be accurately in alignment when bolted together. See Plates XVI. and V.

The channel is suspended by screw bolts from channel irons placed across the trench; so that the whole length may be set at any gradient from 1 in 20 to level. The mode of hinging this at the hydraulic laboratory end and yet making a tight joint is shown in Plate XVI. For the method here adopted the author is indebted to the ingenuity of Mr. P. W. Robson.

By means of the sluice valve in the forebay in the steam engine laboratory it will be possible to work with the lower as well as the upper end of this vee-channel drowned; and it is hoped to make a research on the law of the flow of water in channels under such conditions of accurate alignment, uniform

surface friction, and constancy of hydraulic mean depth that urther light will be thrown on a very intricate but important problem in hydraulics. Earthenware or other pipes may also be laid at any ordinary gradient in the whole or part of this vee-channel and the laws of flow therein experimentally tested.

A special clinometer (Plate XVII.), the joint design of the auther and the Cambridge Scientific Instrument Company, was constructed by the latter, for use with this vee-channel. By its means a uniform gradient of known amount can be attained in every part of the channel; and injurious springing of the same when raising or lowering by unequal screwing of the suspension bolts avoided.

(d) Turbines.

With further reference to the turbines whose great size, as compared with other such laboratory plants, dictated the scope and nature of the water measuring appliances above described, the Thomson Vortex and the Girard turbines, Plates IX. and X., were specially fitted according to the author's specifications with means for the study of the action of the water when passing through them. The turbine wheels may be removed and a dummy or fixed wheel substituted with blades accurately made to the absolute path taken by the water when the turbine is at work, so that an actual measurement of the hydraulic resistances due to surface friction through guide blades and wheel vanes may be made. The head required to cause, say, 280 cubic feet of water per minute to flow through the turbine with the fixed wheel in place will give a close estimate of the above losses; and by moving the fixed wheel into various positions relatively to the guide blades, it is hoped to make some approach to a determination of the loss due to the thickness of the vanes of the moving wheel. It is also proposed to make experiments on the amount of the leakage of water which takes place in the clearance spaces at the sides of the rotating wheel. By placing

small vanes at various points in the current of water, the parallelism of the water lines to those of the vanes can be indicated either by external pointers in the guide passages, or by a potentiometer electrical resistance method in the turbine wheel.

The horse power developed by these turbines is measured and absorbed by a band friction-brake encircling a pulley with water cooled rim which can be coupled to either wheel. (See Plate XI. and Figs. 5 and 6.) The net pull of the band is communicated to a floating lever and is partly balanced by a dead weight and partly by a spring, the deflections of which are recorded on a rotating drum driven from the turbine shaft. Thus a record of the variation of the brake horse power during a run can be obtained. For the principle of this method the author is indebted to Mr. A. L. Mellanby.

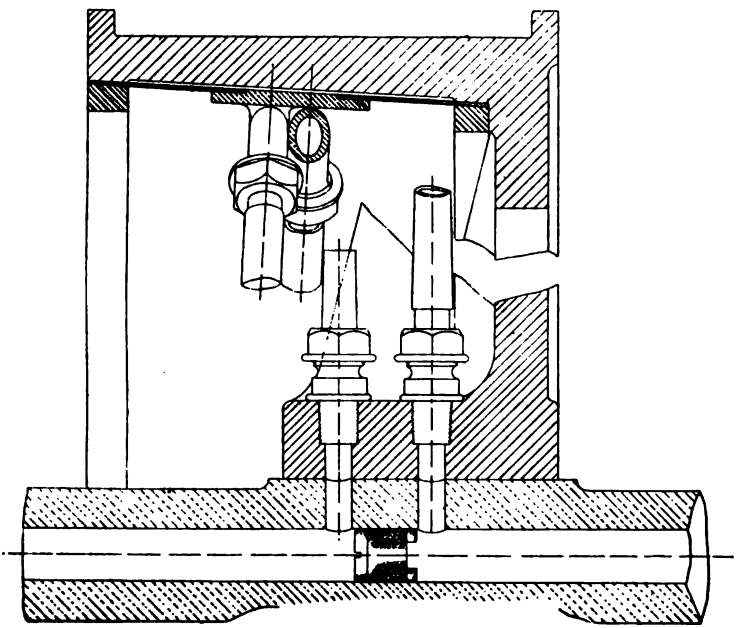

Fig. 5.
Water-cooled Rim for Brake Pulley.

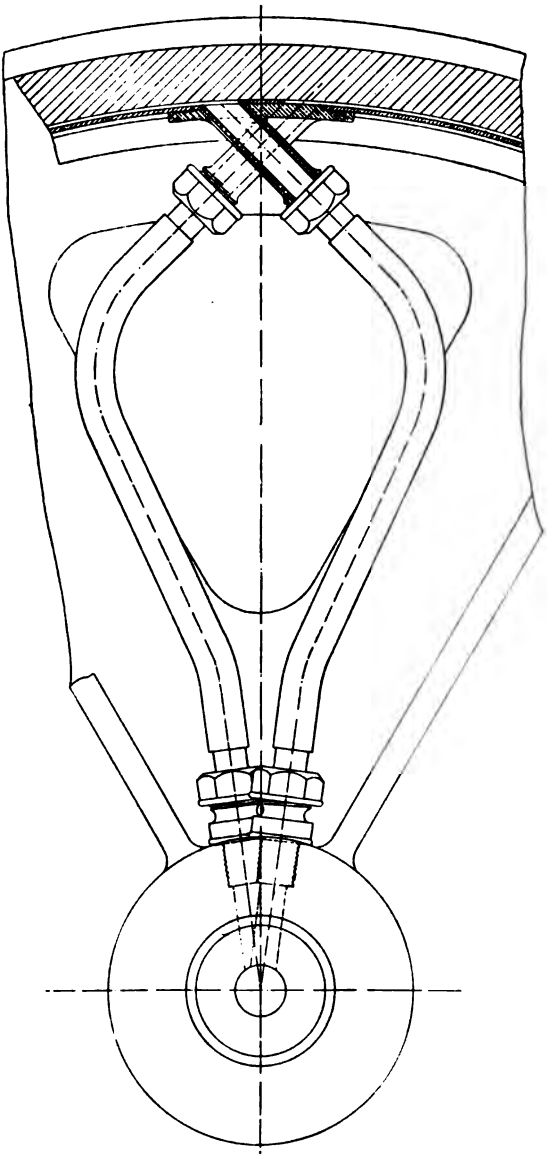

Fig. 6.

The Thomson and Girard turbines and the friction dynamometer, as also an experimental Pelton wheel of 24in. diameter for heads up to 600ft. (Plate XII.) were supplied by Messrs. Gilbert Gilkes and Co., of Kendal. This well-known firm entered *con amore* into the question of the special testing appliances projected by the author for these motors, and some of the fittings such as those for supplying and removing the cooling water for the brake, along the centre of either turbine shaft, are entirely due to the ingenuity of Mr. Gilbert Gilkes of that firm. To him also is due the method of constructing the experimental Pelton wheel 24in. diameter with revolver nozzles and removable buckets. Not only can the best type of bucket be proved by changing them, but by crowding them together or setting them further apart around the wheel, the pitch giving best efficiency can be determined.

The weir and vee-channel and sluice gates were constructed by Messrs. Heenan & Froude, of Birmingham. The six measuring tanks of composite steel and cast-iron (to stand a pressure of 150lbs. per square inch, when used as compressed air reservoirs) were made by Messrs. Geo. Scott & Sons, of London; and the 15in. valves, the small hydraulic cylinders, and valve switchboard for these valves were made by Messrs. Isaac Storey and Sons, of Manchester.

The second reaction turbine above referred to, and which can be fitted in place of the Thomson Vortex turbine, is by Messrs. Hemmer Bros., of Neidenfels, Germany. It is called by them a "spiral" turbine and the special interest of it is that it is guaranteed by them to give a specially high efficiency of performance.

For hydraulic experiments at pressures up to 600ft. head Messrs. Geo. Scott & Sons constructed to our designs a special tank of composite steel and cast-iron. It is shown in Plates XVIIa. and XVIIb., and is of a form intended to keep the lines of the

flowing water as nearly as possible parallel to each other, or in other words to get rid as far as possible of eddying motions. This is absolutely necessary if the phenomena of flow through sharp edged orifices is to be studied. The 12in. supply main increases gradually by the interposition of a conical mouthpiece up to the full diameter of 4ft.; and screens of perforated plates and gauze wire of gradually increasing fineness are placed at intervals across the entire area of the tank.

Water can be supplied to this pressure vessel either from the large tank on the roof up to heads of 100ft.; or, by means of a reciprocating pump (presently to be described) the pressure may be increased up to 300lb. per square inch. The quantity being then however restricted to 300 gallons per minute. By the use of this plant, values of the co-efficients of velocity, of contraction, and of discharge can be determined with sharp-edged orifices up to 3in. diameter.

Measurements of quantity are made by conveying the flow through a switching breeches-piece and the sheet-iron piping to the square basin marked A in Plate VIII. This basin, having been carefully calibrated by filling it with weighed quantities of water, and taking the corresponding heights with the hook gauge, becomes a measuring tank, having a capacity of about 800 gallons per foot, or 5,760 gallons in all.

With the high-pressure tank it is intended also to make experiments on the flow of water through cocks and valves of various types; and through sudden enlargements and contractions, as well as elbows and bends in pipes.

For low heads there is fitted in connection with this jet-tank a large vertical stand-pipe with internal overflow, constructed telescopically so to allow of the upper edge being set to discharge at any required height within the limits of the apparatus. Thus if the loss of head due to the flow through an elbow or bend fitted on the front of the jet-tank is required, the overflow in the

stand-pipe is set to a head corresponding to the velocity required to be maintained through the bend, and a little more water supplied from the high tank than is flowing through the bend, so that a fairly constant small overflow takes place in the stand-pipe accompanied by only infinitesimal changes in the head of water.

Constant pressure in the jet-tank under high pressure is maintained by the uniformity of speed of the pump supplying the water, together with an adjustable spring relief valve discharging from the upper part of the jet-tank, where the latter is kept filled with compressed air from a reservoir supplied by one of the air compressors.

(e) The Experimental Pump.

The exhibits at the Paris and Glasgow Exhibitions of high-speed reciprocating pumps coupled directly, *i.e.*, without intermediate gearing, to electric motors, will be in the memory of members. Professor Riedler, who, along with Professor Stumpf, of Berlin, designed some of these pumps, has long been an advocate of high-speed pumps and air compressors with controlled valves.

As there seemed to be a general indisposition on the part of English pump makers to adopt the high-speed principle for pumps, the Author obtained the sanction of the Committee to the installation in the hydraulic laboratory of a direct connected "express" pump on the lines of those above-mentioned, for the purpose of enabling experiments upon their behaviour to be made in Manchester.

The general arrangement is shown in Plate XVIII. The pump is normally a differential plunger pump with 7in. and 5in. diameter plungers, having 12in. stroke. But it is so arranged that it may be worked with either plunger single-acting, and that the stroke may be varied from 0 to 12in. It is direct con-

nected, through a flexible coupling, to a 120HP 4-pole direct current motor; of which, by means of a large air-cooled rheostat, the speed may be varied between 50 and 800 revolutions per minute; the brake horse-power varying simultaneously from 20 to 120. It may be remarked that the rheostat cost nearly as much as the motor; but that it has almost justified its purchase already in connection with another series of experiments for which the motor has been used.

Four different types of valves were projected for experimental use in this pump; and great credit is due to Messrs. Frank Pearn, the makers of the pump, for the way in which they carried out the ideas shown in the preliminary design which was carefully thought out for the author by Mr. A. L. Mellanby. These various valves are shown in Plates XIX. to XXIII. It will be seen that the mass of the valves of all the types can be changed by affixing to them lead weights; and that the amount of lift can be varied from without the valve chambers. The motion of any of the valves can be communicated by arms, whose ends move with them, to a rocking-shaft fitted across the valve-box, and passing through a stuffing-box in its sides. In this way the actual movements of the valves throughout the stroke of the plunger can be observed outside the pump, and recorded by a pencil on an indicator barrel, if so desired; so that the action of the various types as affected by variation of loading and speed can be studied.

It may be that in the next 50 years the reciprocating type of pump will become quite obsolete, and will be found only in museums; having been superseded by the compound centrifugal pump of the type invented by Professor Osborne Reynolds. Yet close attention to the details of design of reciprocating pumps with consequent improvement of their working, and an increased speed of running accompanied by diminution of size and first cost may help to retard the date of their extinction.

In the same way the advent of the electric light, instead of, as was thought at first, leading to the entire disappearance of gas as an illuminant, has greatly stimulated its improvement, and the competition between the two is to-day probably keener than ever before.

Higher speeds and better volumetric and mechanical efficiencies must then be aimed at for reciprocating pumps; and it may fall to the lot of the experimental pump in this School to help in their improvement in these respects. In seeking to improve a mechanism the first desideratum is a knowledge of the laws of its action; and for the improvement of the design of pump valves, the laws which govern the frictional losses through them, the correct timing of their opening and closure, and the effect of size and shape upon their silent working at high speeds must be investigated. A beginning has been made by several experimenters on the Continent; notably by Professors Bach, Riedler and Stumpf; but until quite recently the researches were restricted to single small valves, not more than two inches in diameter. In order to extend this work and apply it to large single valves and to groups of small ones, the following arrangements were projected in connection with this pump.

The stand pipe for low heads already referred to can be connected to the pump suction, and the water allowed to flow through either the suction or delivery valves or both consecutively at the same speed as it will have when the pump is working. After leaving the delivery valve box the water rises in a conical overflow vessel, and the differences between the levels of the water in this and in the stand pipe gives the head lost by surface friction and bends in the pipes, valve and pump chambers, and by valve resistance. If now the same experiment be carried out with all valves removed, and the water still flowing through at the same speed, the difference of the heads

in the two cases will be that lost by hydraulic resistance of the valve alone.

Gear is also provided on the pump on a plan suggested by Messrs. Pearn for closing the valves mechanically. This consists of screw gearing driving a lay shaft on which adjustable cams are formed. Motion is communicated by the levers, springs, and push rods as shown to the valves which are thus closed at the proper time. Opening of the valves, however, takes place automatically.

When running at the slower speeds the pump draws its water from the square basin (above-mentioned) to which it returns after passing through the jet tank, having previously been discharged under the desired constant head through an appropriate sharp edged orifice.

At high speeds the suction valves of these pumps work under a small head, and it is therefore arranged that in that case the pump shall draw from the 12in. main connecting to the high level tank; a large overflow regulating valve keeping the pressure constant.

(3) MACHINE TESTING LABORATORY.

A floor space of $40\frac{1}{2} \times 25\frac{1}{2}$ or 990 square feet is devoted to machine testing, in the same room as that in which the hydraulic apparatus is installed. The testing of the kinematical and dynamical properties of the machinery of transmission, such as belt, rope, and chain drives; spur, bevel, worm, and screw gearing; and the efficiency of machine tools are the objects to which this laboratory is devoted.

At present a large lathe is installed in the room for the testing of rapid cutting steel. A lengthened series of trials have been carried out therewith during the past session under the auspices of a joint committee, consisting of members of this Society and members of the Technical Instruction Committee, together with the Author. The lathe was loaned to the School,

and the iron castings and steel forgings upon which the cutting was done, were presented by Messrs. Sir W. G. Armstrong, Whitworth & Co. Nearly 200 tests of from 20 minutes to one hour's duration have been made upon these materials with tool-steels by several different makers; the cost of the power and the operating and observing staff, having been borne by the School.

It is for such experimental research work as this series of steel tests exemplifies that the engineering laboratories of the School, by reason of the extensive equipment they possess, are especially fitted.

In connection also with these tool-steel tests, a series of experiments have been carried out by the senior day and evening students on the efficiency of power transmission from the 120HP Schmkert electric motor through two counter-shafts to the 18in. Whitworth lathe. The electrical horse-power or input was measured at the brushes of the motor. A Von Hefner Alteneck transmission dynamometer (made in the School workshops), was placed between the two counter-shafts in order to measure the power actually transmitted through the belt connecting them; and finally, a Prony friction-brake was clamped on to one of the steel forgings to be operated on in order that the work actually given off at the lathe-spindle might be measured. The various frictional losses were by these means determined for every one of the six possible modes of driving the lathe through its back gears; and that for every load from no load to that at which the belt slipped at a constant motor speed; and at three different motor-speeds for the various gears at constant load. The results of these tests appear to be of considerable interest and importance at the present time.

Other machines and pieces of apparatus in this laboratory on which tests are at present being carried on comprise: friction testing machine, for the determination of the co-efficient of dry friction of different metals at various speeds, and under various

pressures up to that of seizing. Apparatus for the study of the action of a Porter pendulum governor by means of a Horn tachograph, and an electric-motor; the governor-sleeve itself operating the rheostat handle. Drilling machine, adapted for testing the relative hardness of cast-iron and steel, fitted with autographic recorder. Apparatus for testing the frictional resistance to slipping of a belt upon various pulley surfaces. Means for the calibration of a 10HP electric-motor, for use as a transmission dynamometer; and apparatus for testing the accuracy of alignment of a lathe.

A research on the durability of the ordinary, and of a new form of tooth for spur-wheels under heavy loads and at high periphery speeds is now in course of institution.

(4) THE GAS AND OIL ENGINE LABORATORY.

Two gas engines and two oil engines each of 20 BHP are installed in this laboratory, which is a fine room 29ft. by 53ft. in the basement. The general arrangement of the plant in this laboratory is shown in Plates XXIV. and XXV.

(a) Gas and Oil Engines.

One of the gas engines, by Messrs. Crossley Bros., has an air compressor for low pressures driven from its crank pin, the capacity being such that air enough for the supply of any of the other three engines may be obtained from it. This air, being delivered into an air holder of 170 cubic ft. capacity from which the engines draw their supply, is measureable by counting the number of strokes of the compressor made during the engine trial and by knowing the volumetric efficiency of the compressor. In short the air compressor becomes an air meter. Back explosions, which constitute the danger of the method of measurement with an air holder, are provided for by a tallow blow off valve as practised by Professor Burstall, of Birmingham,

in his work for the Research Committee of the Mechanical Engineers.

An alternative method of air measurement is provided by three large reservoirs each of about 100 cubic ft. capacity which can be filled with air at high pressure (from the large two-stage air compressor in the steam engine laboratory); and after settling down to a known temperature and pressure in any one of them, can be allowed to flow out as required into the air holder from which the gas and oil engines draw. It can easily be shown that for a given accuracy of the temperature and pressure measuring instruments, the quantity of air used can be more exactly determined when passed through a reservoir at a high that at a low pressure.

The other gas engine is by the National Gas Engine Co., of Ashton-under-Lyne, Plate XXVI., and is specially fitted with thermometer holes in the walls of the cylinder and clearance space for the purpose of their temperature determination under the different conditions of running. The method adopted for getting through the jacket water space is shown in the Plate XXVII. It is the mean temperature across the thickness of the walls in different parts of the cylinder which will be thus determined; not that of the inside surface, which probably varies very considerably above and below this mean during the course of a revolution or cycle. The latter temperature can only be determined by somewhat delicate electrical measurements in connection with thermo-electric junctions placed in small holes drilled nearly through the walls from the outside; as was done by Professor Callendar and the author with a 50 horse power steam engine some years ago in Montreal.

If curves of surface temperature throughout a cycle could be plotted for the principal portions of the cylinder wall of an

internal combustion engine, the quantity of heat given up to them by the working substance not only during the whole cycle but during the various phases of the cycle could be determined; and great light would be thrown upon such important questions as the variation of the specific heat of the mixture with temperature, the rate of flame propagation, and the laws of heat conduction to a metal surface as depending on temperature and density; and the existence and amount of dissociation during combustion.

The two oil engines in the laboratory are similarly fitted; that by Messrs. Richard Hornsby & Sons, Grantham, with specially designed gun-metal thermo-junction protectors, see

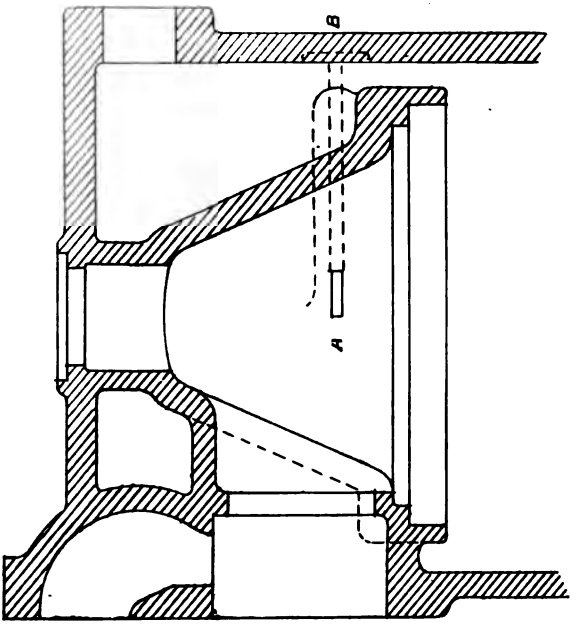

Fig. 9.

Fielding & Platt Oil Engine (Thermometer Pocket.)

Plate XXVIIa.; and with an alternative pair of heavier fly-wheels for speed fluctuation study. The engine by Messrs. Fielding & Platt, of Gloucester, has their very latest type of vaporiser fitted, and has thermometer protectors in the walls as shown in the Figs. 9 and 10.

A 20BHP dynamo by Messrs. Crompton & Co., can be attached by a Raffard flexible coupling to any one of these four engines for braking purposes; and as the current so obtained is delivered to a liquid rheostat, a perfectly steady load can be maintained for any desired length of trial.

Alternatively, if it is desired to study the interaction of governor and fly-wheel and the fluctuations of speed due to varying loads, whether suddenly or gradually applied, this can be very conveniently effected by the use of the rheostat. Two of Dr. Horn's well-known tachographs are available for such work;

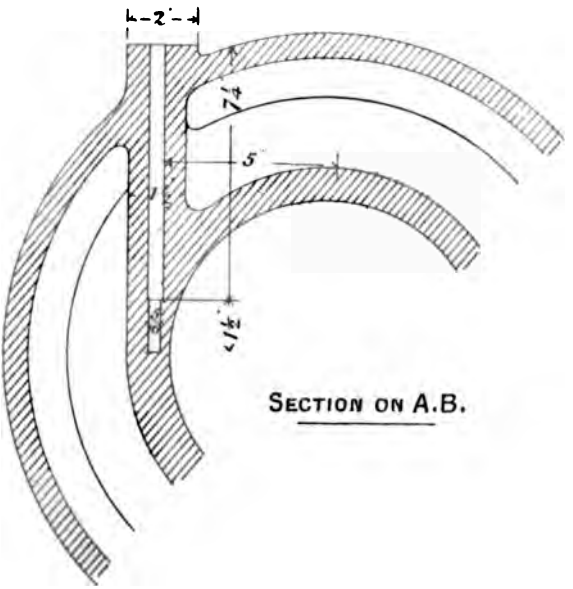

Fig. 10.
Fielding & Platt Oil Engine (Thermometer Pocket.)

one shows variations of speed so small as one-fifth, the other, as one-half of one per cent.

The temperature of the walls, of the exhaust gases, or of the jacket-water can be automatically recorded by the use of platinum thermometers connected to Callendar recorders; and it is hoped also to record the varying temperature of the working substance during the cycle, by the use of a cycle contact maker, and a thick and thin wire thermometer on the plan suggested by Professor Callendar himself.

A fine wet-meter by Messrs. Sawers & Purves, and a standardising holder by J. & J. Braddock, are provided for the accurate measurement of quantities of air or gas.

It may safely be said that there is no more complete laboratory outfit in existence for the experimental study of the gas and oil engine than the one just described; this state of things being due to the judicious liberality with which the Technical Instruction Committee sanctioned the author's proposals.

(b) Ammonia Refrigerating Plant.

In the same room are located two refrigerating plants each of a capacity sufficient to manufacture one ton of ice per day of 24 hours.

One of these was supplied by Messrs. The Linde British Refrigeration Co. Ltd., and is on the ammonia system. It consists of an ammonia compressor of the horizontal double-acting type, belt-driven from the line-shafting in the laboratory. Three special pistons are supplied for varying the clearance volumes from the normal to $\frac{1}{8}$in. or $\frac{1}{4}$in. at each end; and the barrel and covers of the compressor have fittings and openings in the walls for inserting thermometers. The valves are fitted with special indicating gear for studying their action. The piston rod is bored down the centre to permit of the insertion of a Callendar

thin wire thermometer for measuring the temperature of the ammonia during compression and evaporation.

Thermometer fittings are also arranged for on the inlet and outlet pipes to the compressor for taking the temperature of the ammonia before and after compression, see Plate XXVIII.

The ammonia condenser is of the submerged type and consists of three different coils of lap welded wrought-iron tube wound each in one length so as to avoid inaccessible joints, Plate XXIX. These coils, each of $1\frac{3}{16}$in. bore, are of 200ft., 150ft. and 100ft. total running length; the first named of 78·6 square feet area being the normal coil for this size of compressor. Instead of the condensing water being allowed to flow vertically past the coils; it is arranged, by having sets of half diaphragm plates of galvanised sheet iron for each coil which are inserted between each thread, that it shall circulate spirally with or against the coil in one continuous passage from bottom to top. The object of this arrangement is to secure a definitely directed circulation of the cooling water at a known speed outside the ammonia coil; so that the effect on the rate of heat transmission across it of different speeds of circulation may be observed and recorded. Thus it may be found that an abnormally small coil with a high rate of water circulation is just as efficient for cooling purposes as the larger coil with the slower speed.

The Evaporator, see Plate XXIX., is of quite similar design so far as the coils and diaphragm plates are concerned; but has in addition a special water-tight jacket space $\frac{1}{2}$in. wide around the sides, and a space at the bottom fitted with slag-wool. The jacket-space is to be kept at a constant temperature by a continuous supply of water, so that by measuring the quantity supplied and its fall of temperature during passage through the jacket, the loss of refrigerating effect due to radiation from the surroundings may be closely allowed for.

The special brine pump is of great size, being capable of delivering as a maximum, 1,200 gallons of brine per hour. This pump has an adjustable length of stroke and three speed cones, so that any rate of circulation of brine within the above limit can be obtained. It is driven by belt from the laboratory shafting.

An ice tank to hold 20 terned steel moulds for blocks of ice, each weighing about 56lbs., is part of the installation. This tank is fitted with a propellor for circulating the brine amongst the ice moulds; the propellor being driven by belting from the line shafting.

Mr. T. B. Lightfoot, of the London Linde Company, took the greatest interest in the designs and execution of this plant. The Author takes leaves here to express his thanks to him and the other members of his staff, for the trouble they took in carrying out and improving upon his suggestions.

(c) Carbonic Acid Refrigerating Plant.

The second plant is one in which carbonic anhydride is used as the working fluid on the system of Messrs. J. & C. Hall, of Dartford. In the standard type of this machine, the evaporator (or refrigerator) occupies a central portion of the base of the machine, and is inside the condenser. It is insulated from the latter by means of double walls filled in between with hair felt. In the experimental plant, the evaporator is a quite separate vessel from the condenser; and both are fitted so that three separate lengths of coil may be used. The way in which this is effected is shown in the Figs. 11 and 12, from which it is seen that the carbonic acid coils, three in number, are formed to the same helical pitch and diameter as the brine or water circulating coils, and threaded within them. This method is the invention of the late Mr. Alexander Marcet, of the Dartford firm.

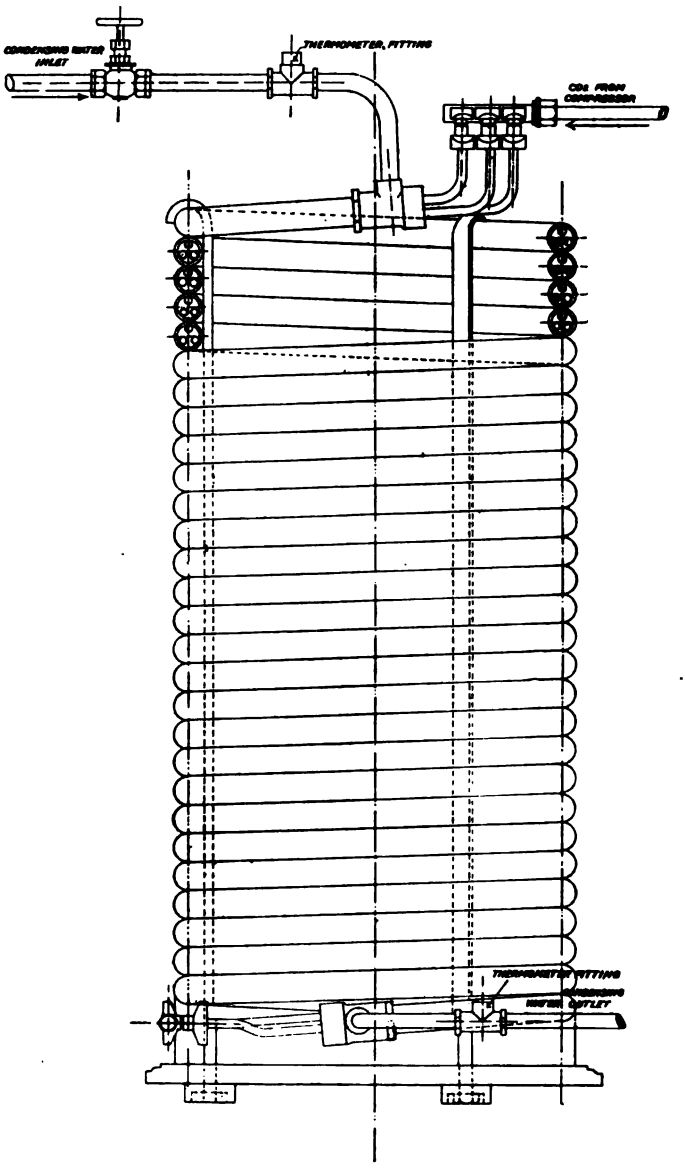
CONDENSING WATER INLET
THERMOMETER, FITTING
CO2 FROM COMPRESSOR

Fig. 11.

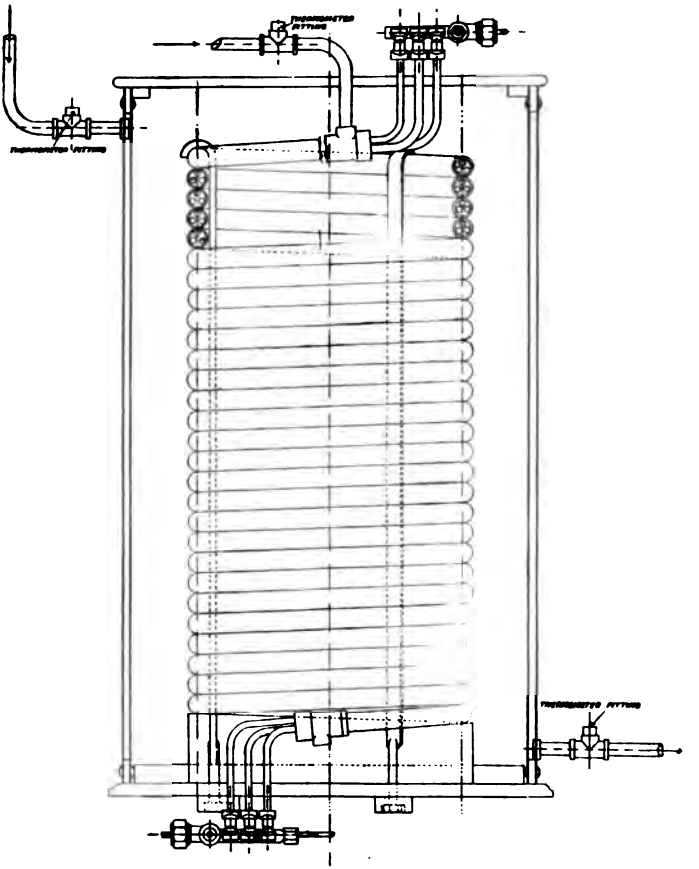

Fig. 12,

In this way it is possible: (1) keeping the brine circulating at an invariable speed, to study the effect of different areas of coils upon the rate of evaporation or condensation of the CO_2. The carbonic acid may be forced through the spiral coils, one, two, or three abreast; the speed of circulation and the area of pipe per pound of working fluid being thus varied at pleasure. (2) keeping the speed of the carbonic acid and its coil-area both constant, the effect on the rate of transmission of heat through

the coil may be studied as affected by different speeds of brine circulation. The large brine pump of the Linde plant can therefore be diverted for use with the Hall refrigerator so that speeds of the brine up to four or five times the normal may be attained. Plate XXXI. shows the first proposal for the experimental plant, which was given up in favour of Mr. Marcet's design.

The cooling effect of the brine circulated (normally to a cooling chamber or to an ice-making tank) is to be measured by the heat it takes up from a coil of wire heated by an electric current, on the plan used by Prof. Ewing, at the Engineering Laboratory, Cambridge.

Thermometers can be inserted at various points in the circuit, as also in the compressor cylinder walls; provision for this having been made in the supply by Messrs. Hall of a special compressor casting with pockets in three places in the ends and side of the cylinder. The arrangement is shown in Plate XXX.

This compressor is driven by belting from the line shafting of the gas and oil laboratory, and can therefore be operated by any one of the engines. It can also be driven by the Crompton dynamo working as a motor from the electric mains of the building lighting and power circuit.

(5) MATERIALS TESTING LABORATORY.

This laboratory has a floor area of 1810 square feet (74 × 24), and is devoted to the testing of the materials of construction, such as iron, steel, copper, the alloys, stones and masonry, bricks and brickwork piers, timber, and the parts of machines and structures. The general arrangement of the laboratory is shown on Plate XXXII.

The Board of Trade do not accept, as sufficiently accurate, tests made in tension or compression with an ordinary hydraulic press. For rough tests it is sufficient to find the load on the

test piece by simply multiplying the ram area by the gauge pressure, but a considerable uncertainty is introduced in that case, especially at light loads, by the cup-leather or gland-packing friction.

Testing machines for accurate work have therefore invariably a means for actually weighing the load on the piece which is being tested.

An hydraulic ram usually exerts the pull or thrust on one end of the specimen, whilst the other end is connected by links to a lever (or system of levers), upon which a rolling weight of known amount is adjusted to exactly balance the force which the test piece is sustaining. Thus the net pull is known, and the unknown frictional force eliminated.

(a) 50-ton Horizontal Wicksteed Testing Machine.

A very usual type of testing machine in this country is that designed by Mr. J. H. Wicksteed, and manufactured by Messrs. Joshua Buckton & Co. The machines of this firm, with a single lever, are made up to 100 tons capacity, the specimen being vertically disposed with the pulling cylinder below and the lever above. Horizontal machines in which the specimen and lever are both horizontal, usually have a bell-crank lever interposed between specimen and main weighing beam. An example of this type of machine of 50 tons capacity is installed in this laboratory, and its general features are shown on Plate XXXIII.

This type of machine is well known and need not be described in particular. An attachment was however designed and fitted by Mr. Wicksteed, at the request of the author, for calibrating the machine at any time during its period of service by applying dead weights of known amount. This consists, as shown on the right of the side elevation of the machine, of a right-angle lever and a cross beam, from which two tension rods depend into trenches in the floor of the laboratory.

In each trench is placed a bogie, running on rails, loaded with ten one ton weights. The weights are applied two tons at a time by being suspended from each end of the cross beam in succession, as their supports are screwed down out of the way by handwheels on the bogies. The vertical pull of the dead-weight is converted into a horizontal thrust against the knife edge cross-head of the machine by means of the knee lever; a piece of hard steel being interposed resting on two rollers. By these means a load of ten tons can be actually imposed on the lever system at any time, and the reading of the jockey weight on its steelyard verified. The levers are free to swing all the time, and the sensitiveness may also be tested by this method.

(b) Amsler-Laffon Testing Machines.

Another type of machine exemplified in the laboratory is that elaborated by Prof. Tetmayer, now of Vienna (formerly of Zürich) in conjunction with the firm of J. Amsler-Laffon & Son, of Schaffhausen, Switzerland. (Fig. 7.) In these machines the load on the specimen is determined by multiplying the area of the hydraulic plunger by the pressure acting upon it. No error due to cup-leather friction is introduced, however, as the plungers are not packed, but simply float in thick oil, such as castor oil, which prevents metallic contact between ram and cylinder, and is allowed to leak slowly past the former. Great care is taken in boring the cylinder and machining the ram to get a fine fit; and, when considered necessary, the ram may also be rotated to and fro in the cylinder during the test so as still further to eliminate any small friction there may be in the axial direction. The principle underlying this method of working is due to Amagat; and is very commonly employed for gauge and indicator-spring testing machines. It is well known to engineers that a shaft rotating in horizontal lubricated bearings will very readily move endwise. The smallest force is sufficient to induce a slow axial

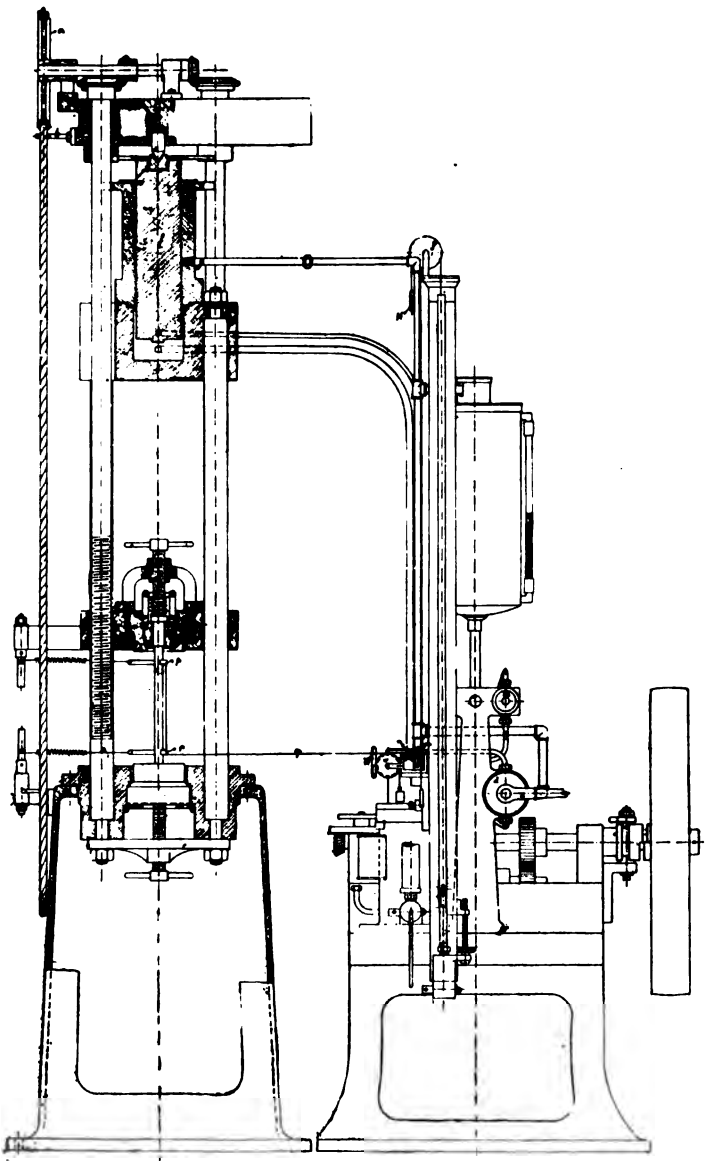

Fig. 7.

25-ton Tension Testing Machine, by Amsler-Laffon.

motion in such a rotating piece. The reason for this is obvious if we remember that the direction of the force of frictional resistance which a body opposes to motion is exactly in the opposite directian to that motion, so that the force required to produce axial motion bears the same proportion to the force producing circumferential motion as the axial speed bears to the speed of turning of the surface of the piece.

In the Amsler-Laffon testing machine this principle is applied not only in the main pulling cylinder, where the ram can be rocked to and fro while under pressure, so as to eliminate axially directed friction, but also in the pressure reducing apparatus for enabling the high pressure in the pulling cylinder to be read off as that due to a column of mercury in an open tube about six feet long. As shown in Fig. 8, the pressure reducer, a pipe leading from the pressure cylinder connects to the flange A and produces the same pressure in the space B as in that cylinder. During working, valve W is clored; it serves for unloading the specimen, and emptying the pulling cylinder of oil, viâ the pipe X to the oil resevoir. The pressure in B tends to press pistons C and D down. The sleeve D can be placed in one or other of two positions. If its collared-end rests on the bottom of B, the ratio of areas is that of the inner piston C to the ram E; if on the other hand, piston E is raised so that the bottom end of D rests upon it and is clear of the bottom of B, the ratio of areas is obviously that of pistons D to ram E. Ram E floats upon a thickness of oil which rests upon quicksilver, connected by pipe H and cock Q to the mercury column I. For small specimens, the pistons C and D press together against E; for large specimens, ram E is lowered by withdrawing oil from cylinder G by means of cock L, and hand-pump K, until D's collar rests on the bottom of B. The position of E, and the reducing ratio. are indicated by the little rod S. Two scales, one on each side of the celluloid mercury

holder or pipe I, are provided for the two cases. The float M, shows the maximum reading attained during a test.

Pressure is applied by the rotary hand-pump, shown in Plate XXXIV.; so that each machine is quite self-contained.

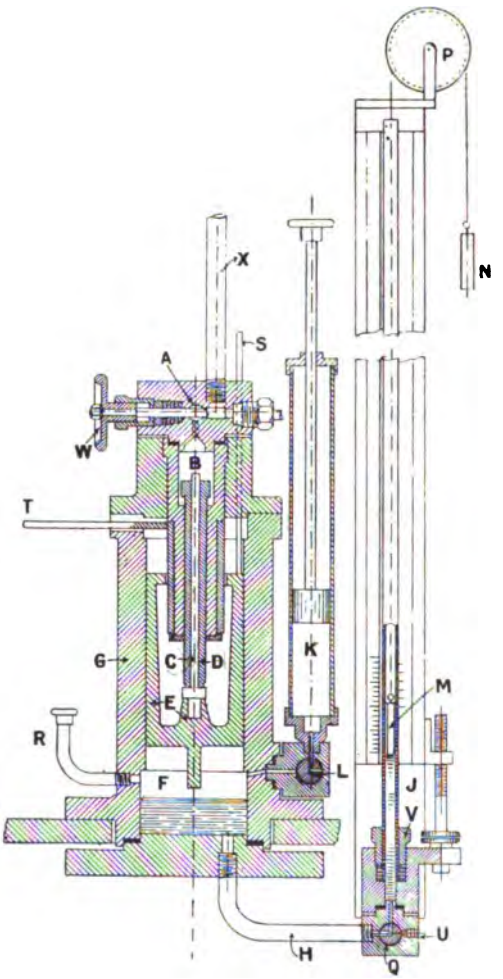

Fig. 8

The 25ton tension, and the 30ton beam-bending machines, Plate XXXV., in the laboratory, are operated by the rotary pump illustrated; whilst the 30ton compression machine is put in operation by a small ram, worked by a handle and screw. It also has its own pressure reducer and mercury column.

These machines have proved themselves handy and accurate; although the pump connections seem unnecessarily complex.

(c) 750-ton Compression Machine.

The third method of eliminating cup leather friction in the measurement of the load on a test piece, which is exemplified in this laboratory is that in which a diaphragm is used in conjunction with a mercury column.

This method, which has been strongly advocated by Professor A. Martens, of the Prussian Government Testing Establishment at Berlin, has been here applied to a compressive machine for loads up to 750 tons. The machine itself consists of an ordinary cotton press as used in this district modified in the way shown in Plate XXXVI. A strong circular casting is placed upon the straining beam between the pillars at the lower end of the machine. The platten carrying the specimen to be tested rests upon a ram fitting the bored interior of this circular casting accurately. A sheet copper diaphragm connects the ram to the casting and confines a small quantity of rather viscous fluid below it. This fluid gives to the top of a glass gauge fitting which it half fills; the lower half being occupied by mercury. This mercury is supplied from a large strong vessel below and has a connection to a mercury column 108ft. long placed in the elevator well of the building. The pressure below the diaphragm is thus indicated by the height of the column of mercury in the tube, and as this pressure may reach 600lbs. per square inch, and the diaphragm is 3ft. in diameter, a very considerable load may be

sustained and measured within the range of the mercury manometer.

Special apparatus, the joint design of Prof. H. L. Callendar, F.R.S., and the author, have been provided on the machine, enabling the diaphragm by its small rise and fall, not only to automatically adjust the height of the mercury in the column to the pressure at every moment exerted by the specimen, but also to record this pressure upon a rotating drum by the use of a Callendar recorder, as made for platinum thermometers. In this way the only duties of the operator are to apply the load at the desired rate by admitting pressure water above the ram, and to take observations of the compression suffered by the specimen as the test goes on.

The celebrated Emery testing machine was constructed, as is well known, on the diaphragm principle; but in the experience of the author the sensitiveness of the weighing apparatus was carried to such a degree that one operator was constantly employed in attending to that part of the test alone, and another had to be in attendance upon the pulling cylinder and the extensometer.

This apparatus has not as yet been connected up, owing to the pressure of other work: but it is expected to be in working order in the course of the present summer.

Water at pressures up to one ton per square inch is provided for this and the 50 tons Wicksteed machine by an accumulator and intensifying pump, which works automatically, from the 1,100 pounds City hydraulic mains.

In connection with the design of the various plants for this new School, the author desires to acknowledge his indebtedness to the ability and untiring energy of Mr. P. W. Robson, who acted as his chief assistant throughout. His sound practical views and skill as a designer were of the greatest benefit during the course of the work.

In concluding this necessarily somewhat curtailed description of so extensive a laboratory equipment, one question of a practical character naturally arises in the mind:—*By whom is the extended programme of experimental work indicated by such an equipment likely to be carried out?*

Physical limits are set to the powers of even the most liberally endowed staff, and the possibilities for carrying out useful research work with such students as now usually attend our Technical Schools,—consisting, as they do for the most part, of mere school boys and raw untrained youths,—are very restricted. Help must be looked for from those who will most directly benefit from the results to be obtained, the engineering employers.

It is earnestly to be hoped that, conjointly with the unification of educational authorities at present taking place, the leaders of industry will make their voices heard and their influence felt in arranging for some more rational system of engineering education than what has hitherto been possible.

The plan which the author believes, from his experience in the workshop and in the college, to be the best, is that in which a term of workshop practice, accompanied by private or other study of elementary mathematics and science, precedes entry upon the college course. A youth can very well learn to chip, file and turn, to make patterns and castings, and to fit and erect a machine or engine without any knowledge of the theoretical principles of engineering; but it is a hopeless task on the other hand, to try to teach engineering theory, or to attempt experimental work of any but the most elementary character with boys fresh from school, who do not know the names or the functions of even the most elementary parts of machines.

The method now almost universal, of accepting such youths in Technical Schools, is largely a policy of expediency; and has resulted from the conditions prevailing in industrial life, whereby

the older the boy is the greater is his market value. All that it has hitherto been possible to do with such a student, is to teach him science, and drawing; and to explain to him what the commoner machines are for, how they work and what are the names of their various parts. If engineering employers consider this a desirable consummation to be aimed at; then so called Technical Schools will no doubt be continued and maintained to carry on this drudgery, they ought however, to be called trade schools, as more truly indicating their real character.

The author is bound to confess that he is unable to see any advantages, at all events to the nation at large, accruing from this system. No doubt it is better for the employers that the process of sieving out useless material should be done in Technical Schools at the public cost, rather than in the workshops at their expense. This form of argument must also receive due consideration, for the object of a workshop is to make a profit on the capital invested in it. The author therefore wishes to put the matter on this very ground of practical profit and loss; and to assert that it will be found to be a remunerative investment to an employer if he will choose one or two of his senior apprentices who show aptitude both in the workshops and at their evening studies; and by enabling them to attend a Technical High School, such as the City of Manchester now possesses, for two or three sessions; he will endeavour to secure a man not only highly trained in engineering theory; but specially skilled in the carrying out of experimental research work directly connected with industrial processes.

The paper was preceded by a visit of the members to the Municipal School of Technology, after which the party returned to the Grand Hotel. On the motion of the President (Mr. E. G. Constantine), seconded by Mr. Henry Webb, a Vote of Thanks was accorded to the Technical Instruction Committee of the

Manchester Corporation for the courtesy extended during the afternoon, and a similar compliment to Dr. Nicolson for his able paper.

Mr. J. H. Reynolds, the Principal of the School, and Dr. Nicolson briefly responded.

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42 Plates follow illustrating this Paper.

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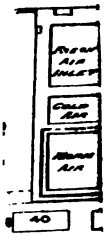

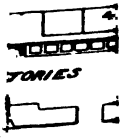

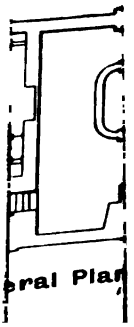

Plate II.

NEERING LABORATORY

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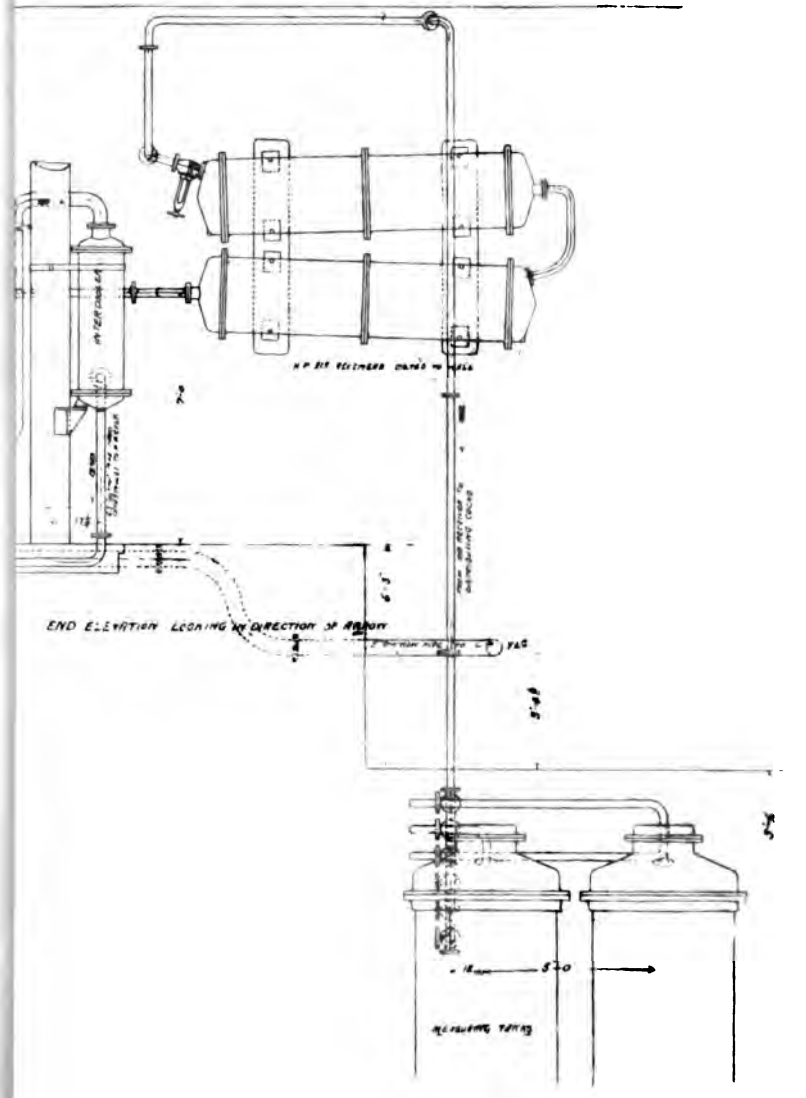

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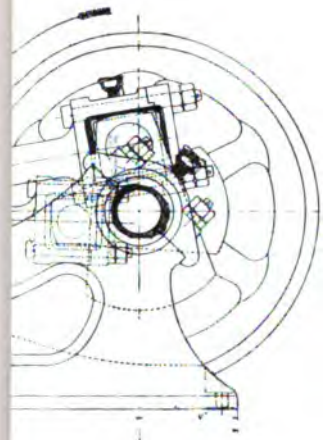

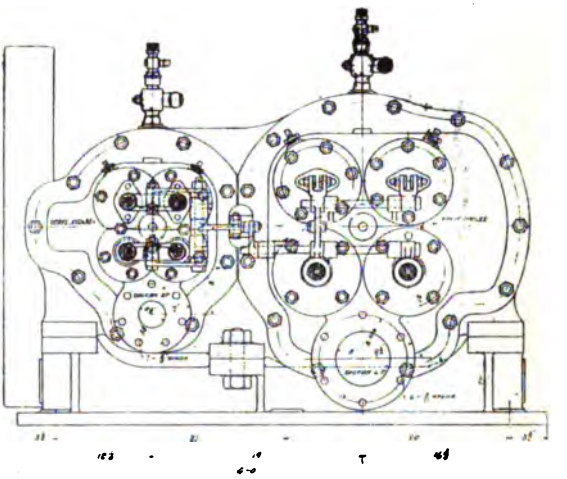

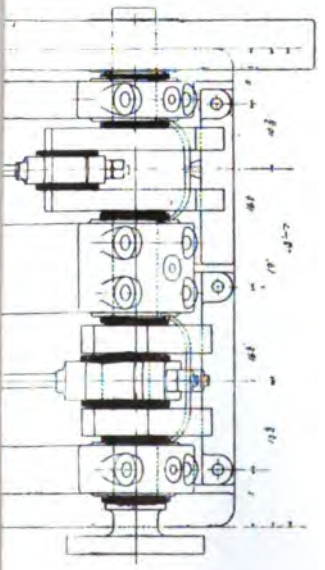

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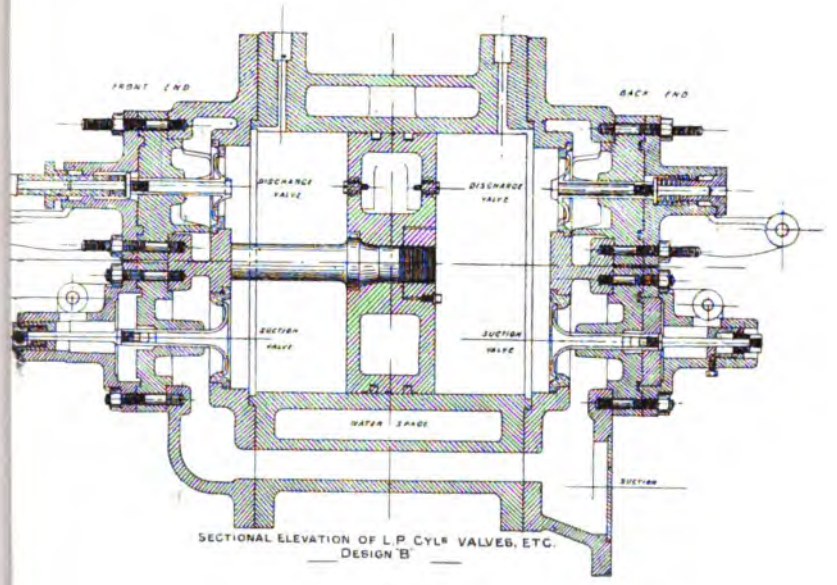

SECTIONAL ELEVATION OF L.P. CYL^R VALVES, ETC.
DESIGN "B"

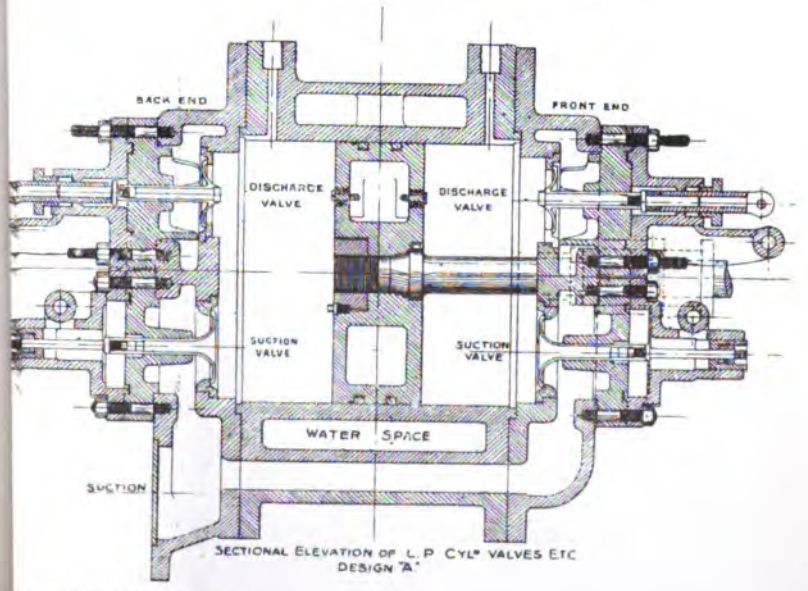

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Plate VI.

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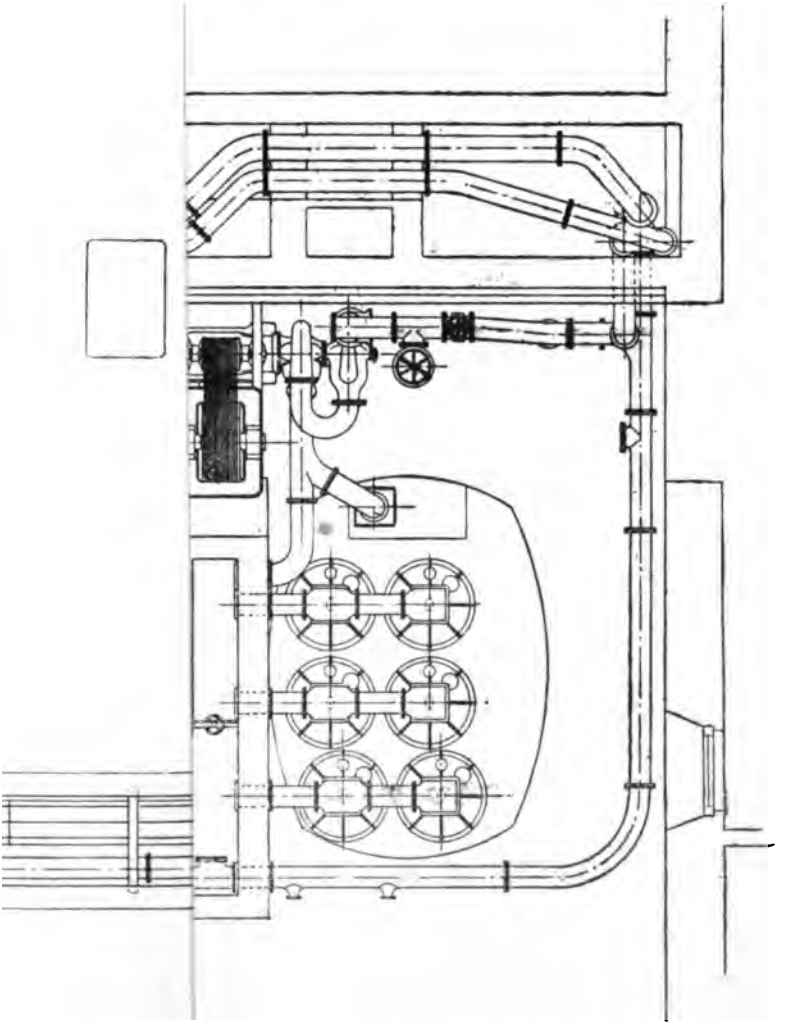

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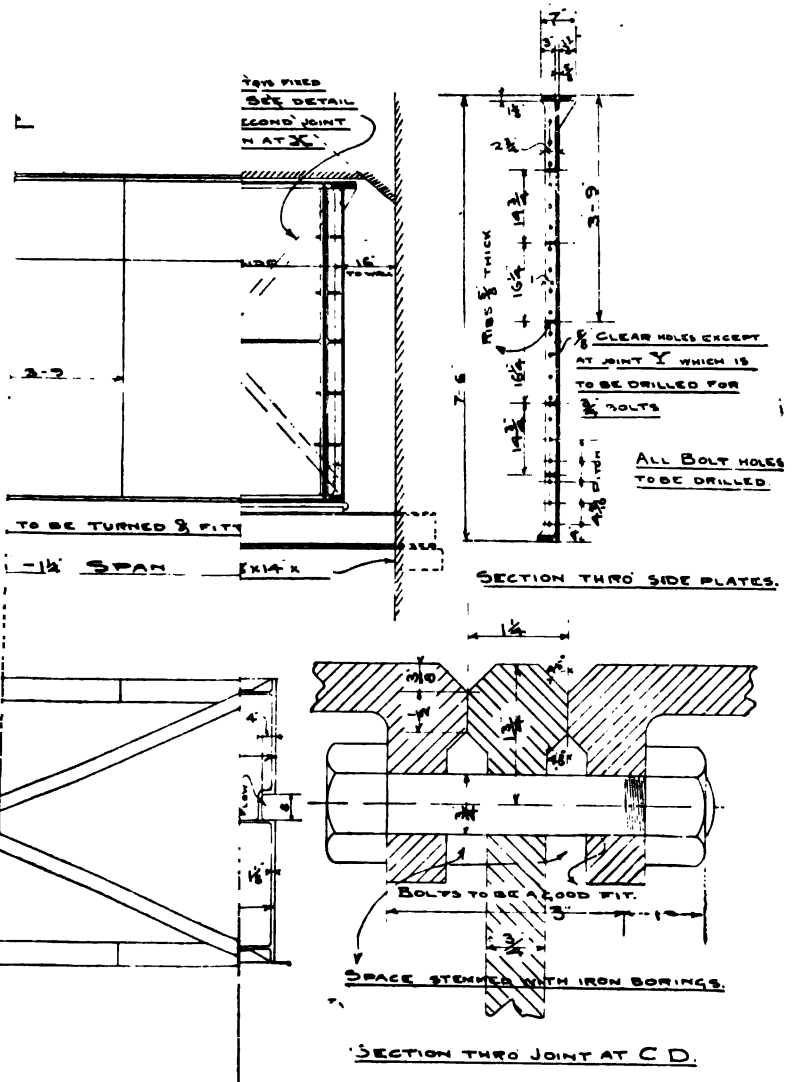
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Plate VIII.

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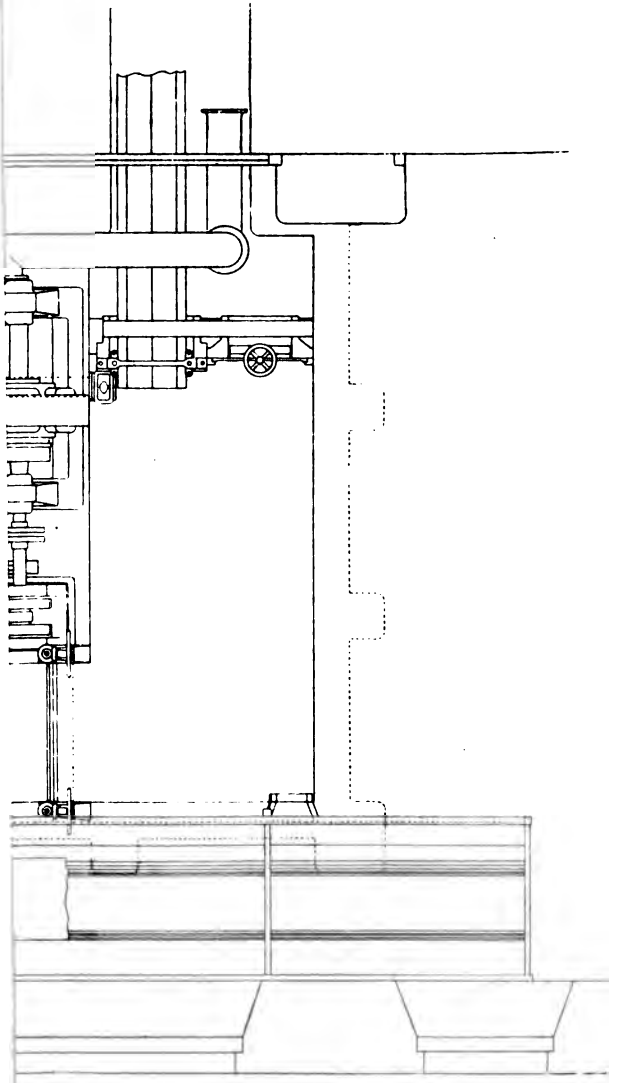

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Plate IX.

ɪING LABORATORY

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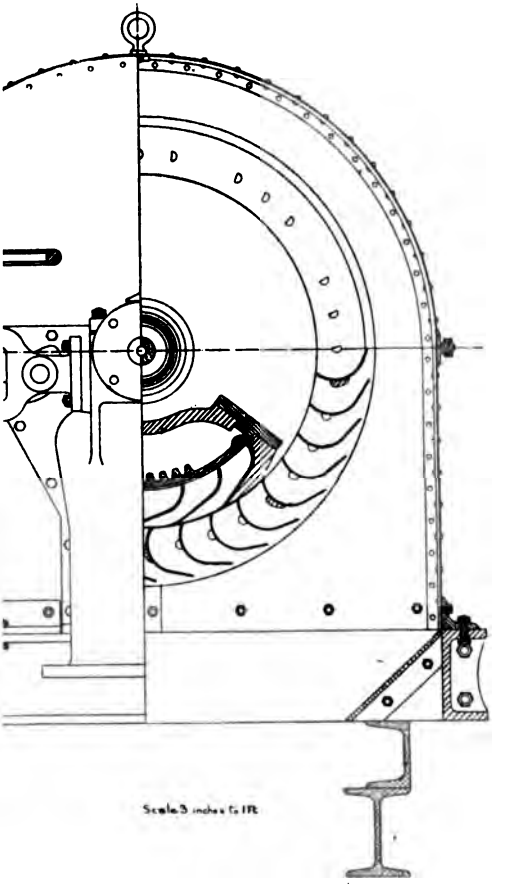

Plate X.

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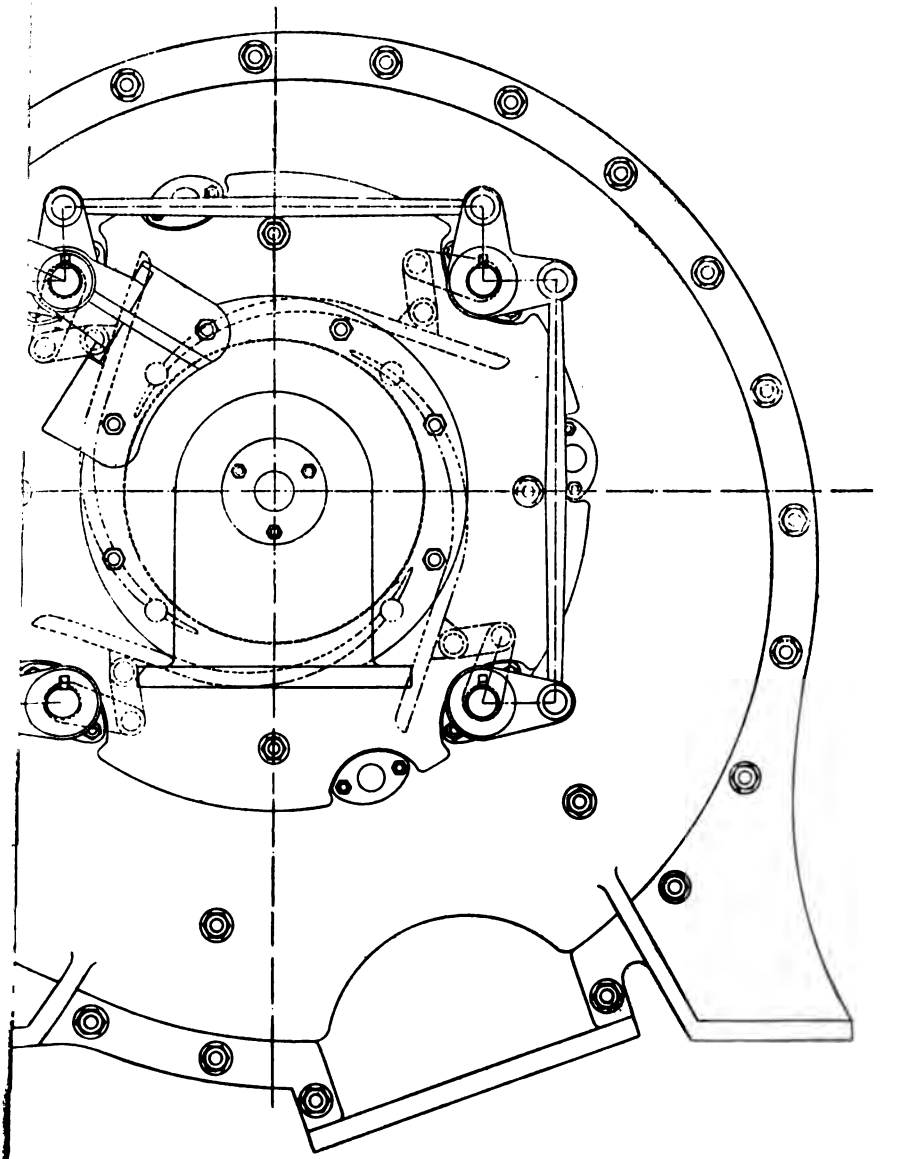

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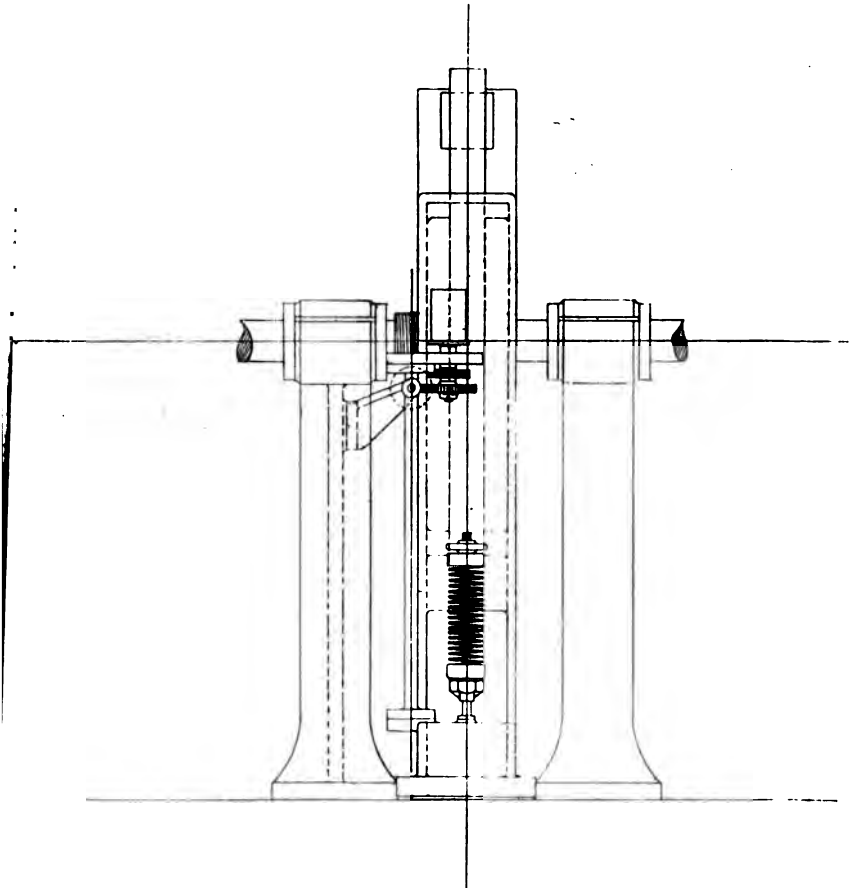

FIG. B.

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Plate XIII.

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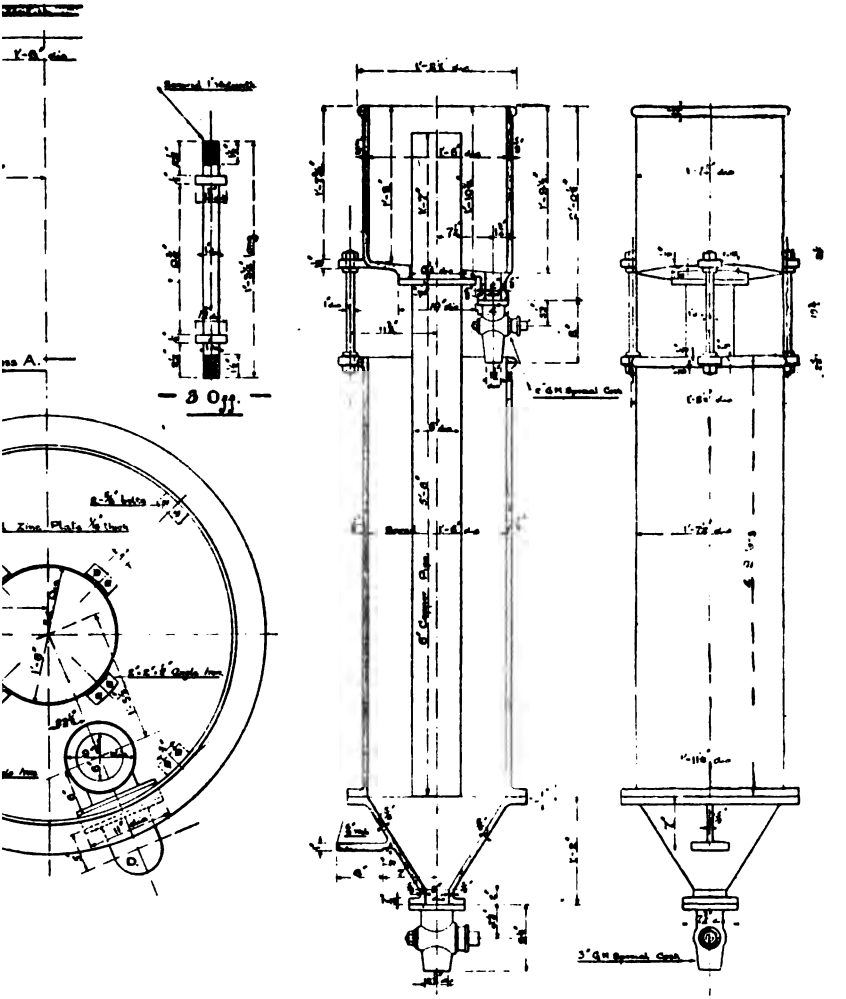

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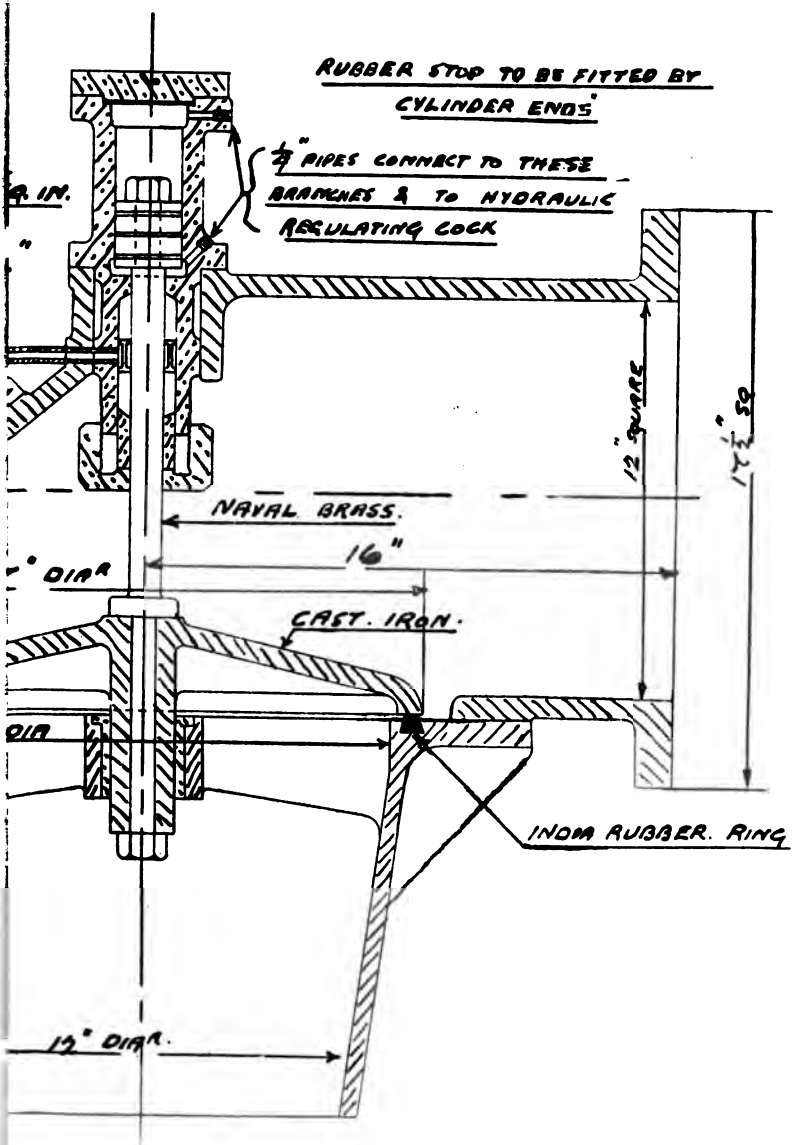

Closed by Hydraulic Pressure for Measuring Tanks.

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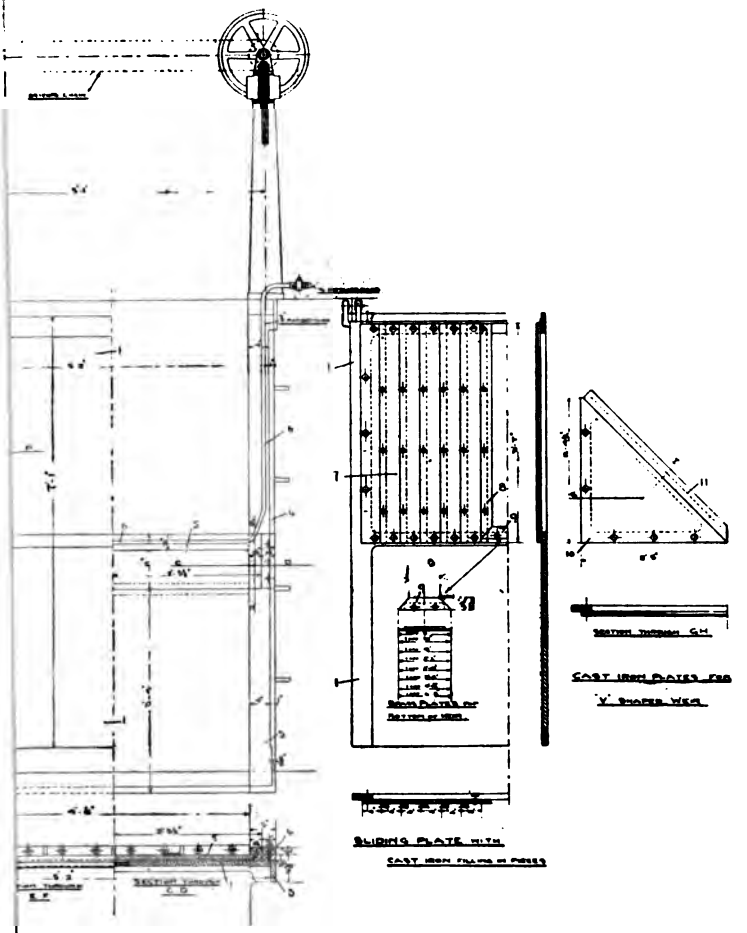

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Plate XVa.

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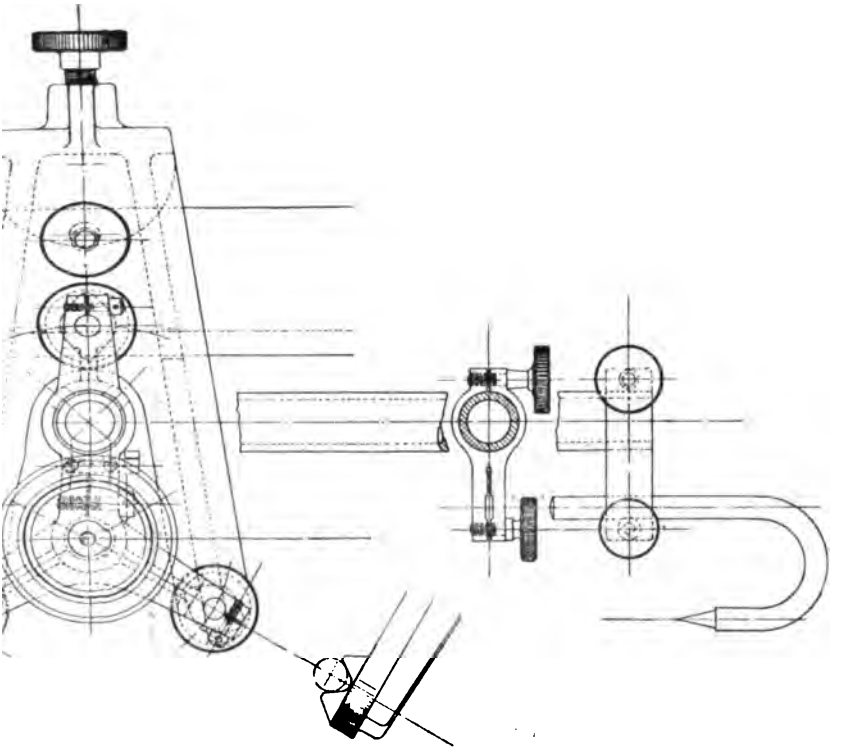

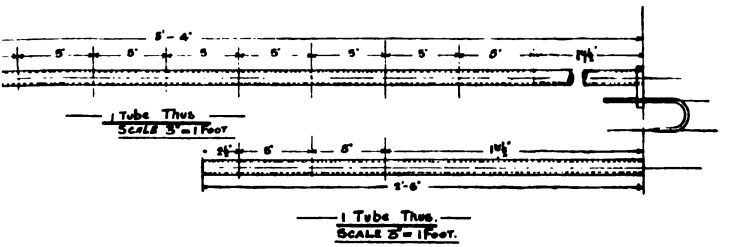

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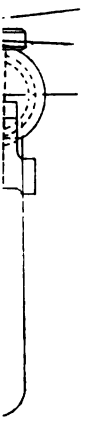

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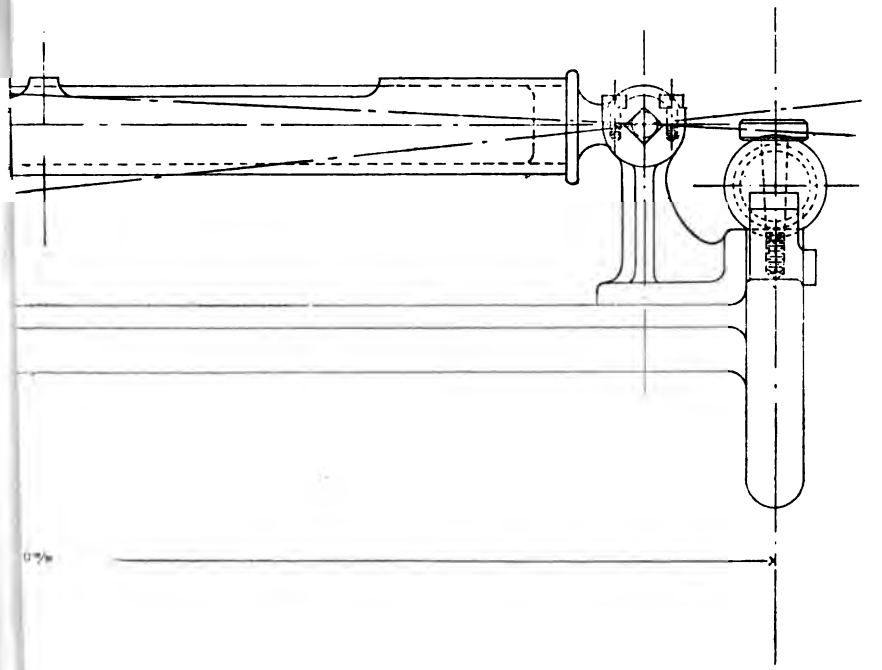

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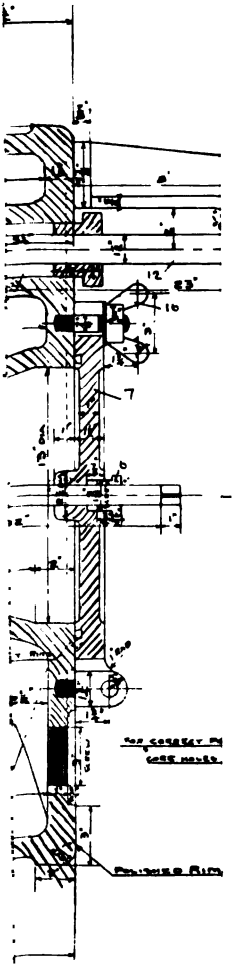

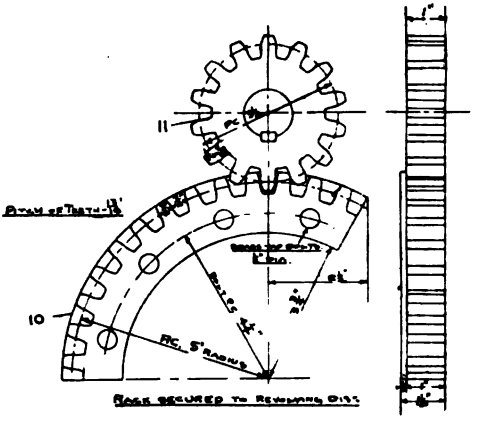

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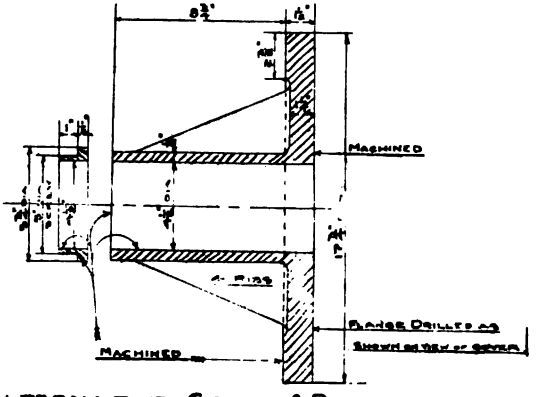

ALTERNATIVE COVER & BUSH

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Orifice Casting

Plate XVIIb.

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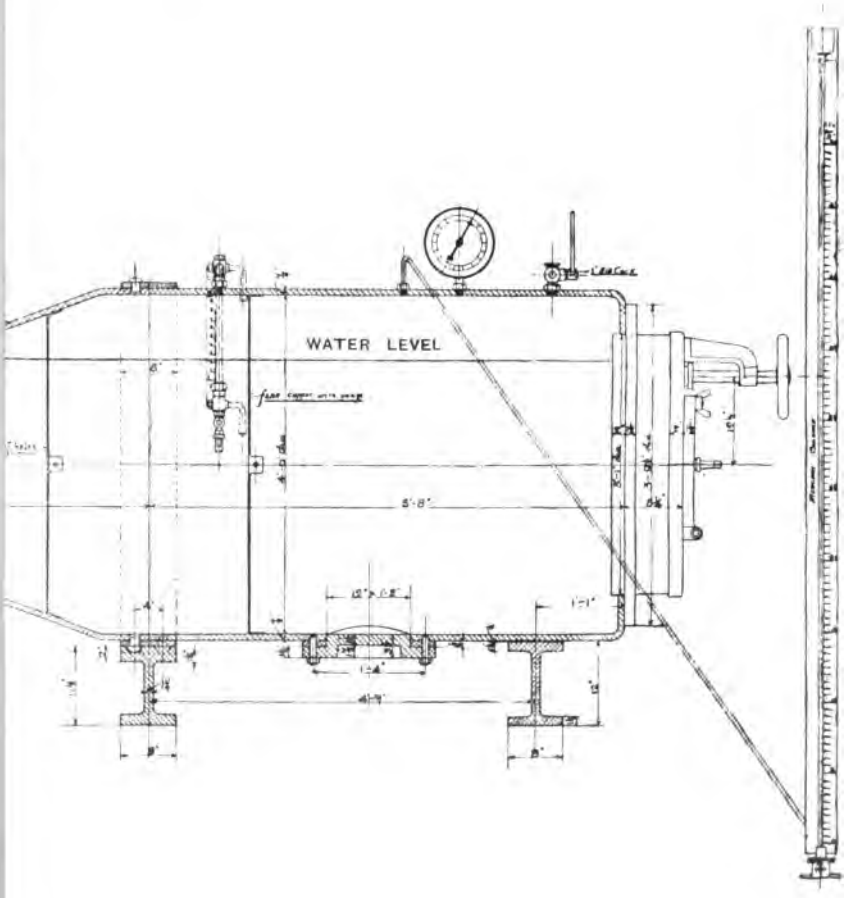

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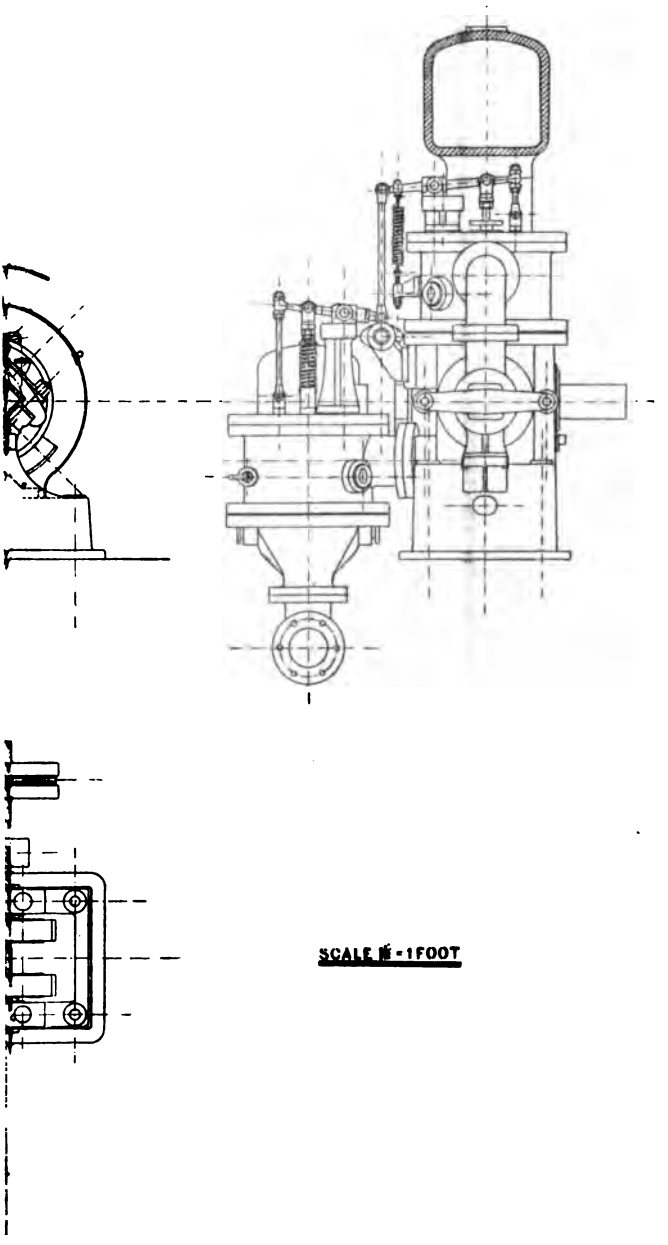

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Plate XIX.

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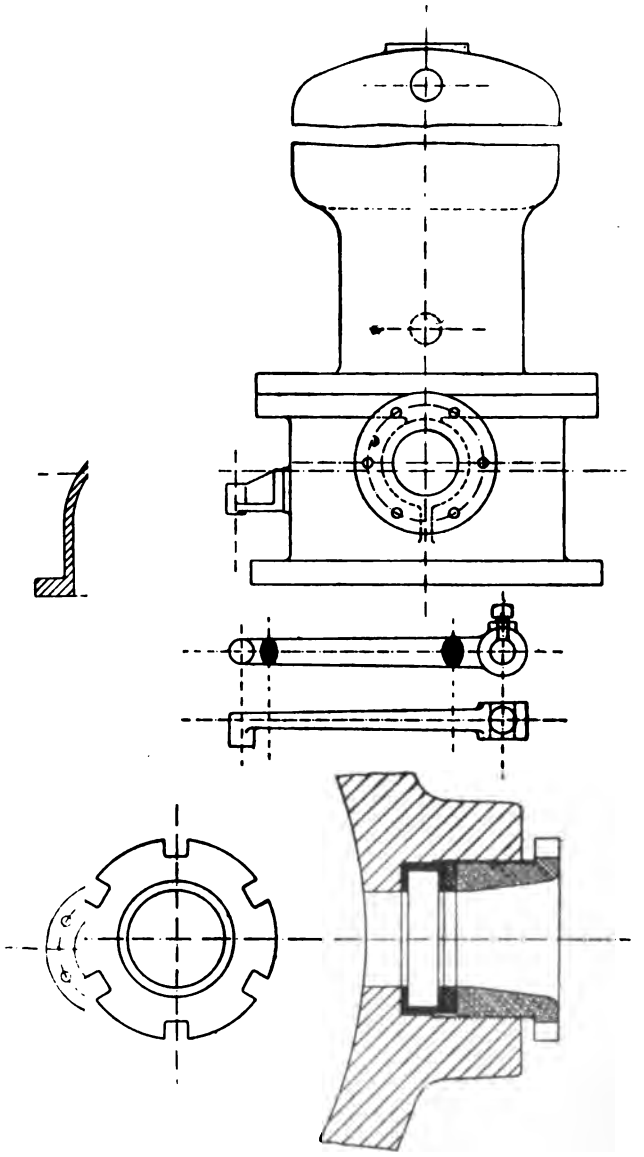

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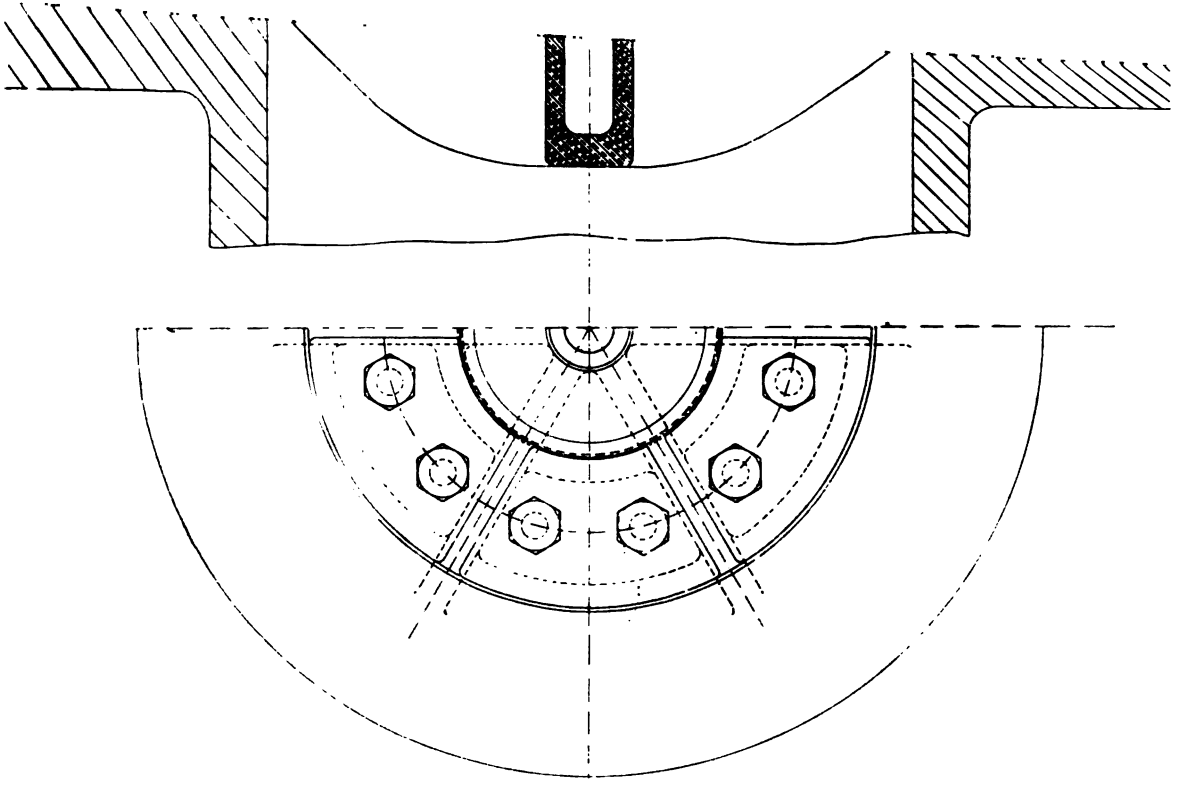
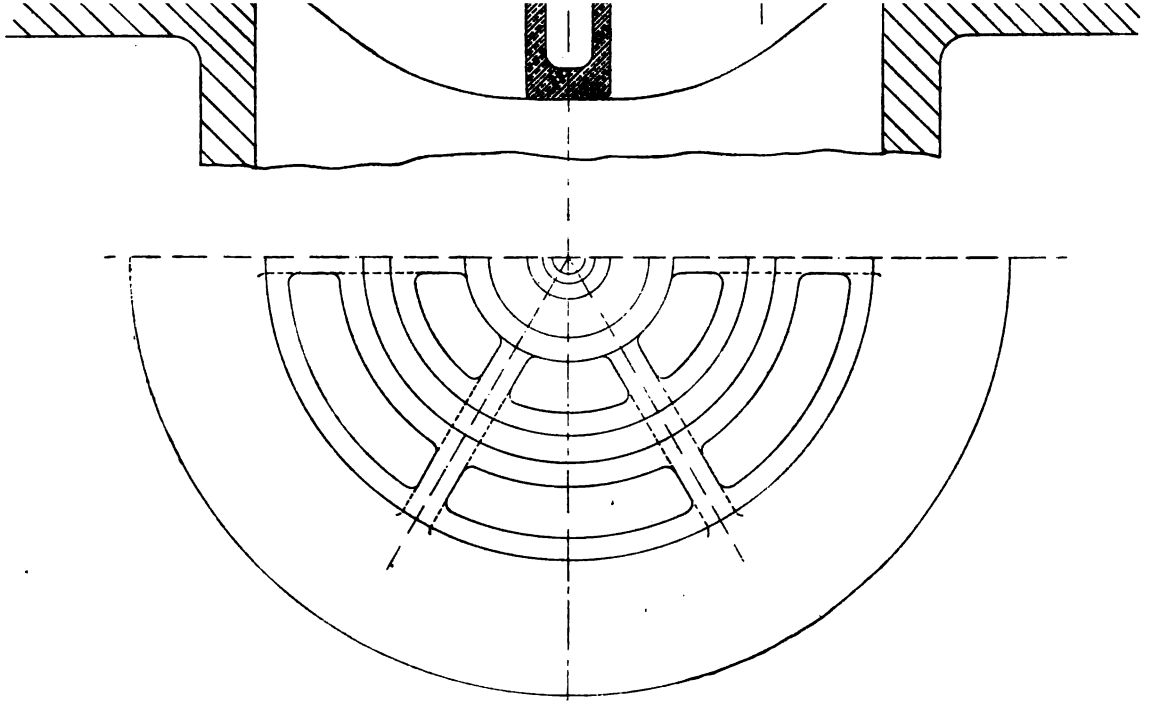


Large Valve with Leather Seating for High Speed Pump. Type A.



Large Multi-ported Valve for High Speed Pump. Type B.

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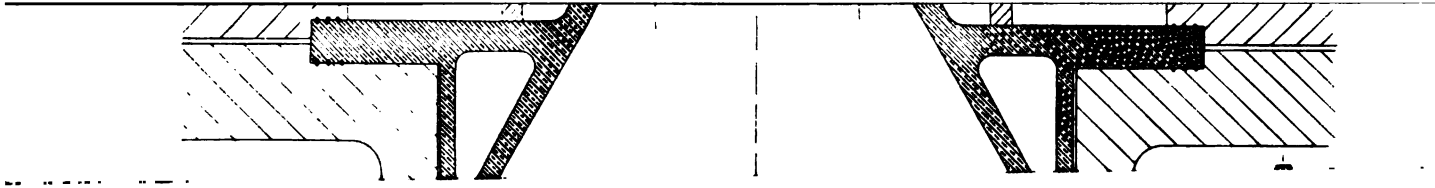

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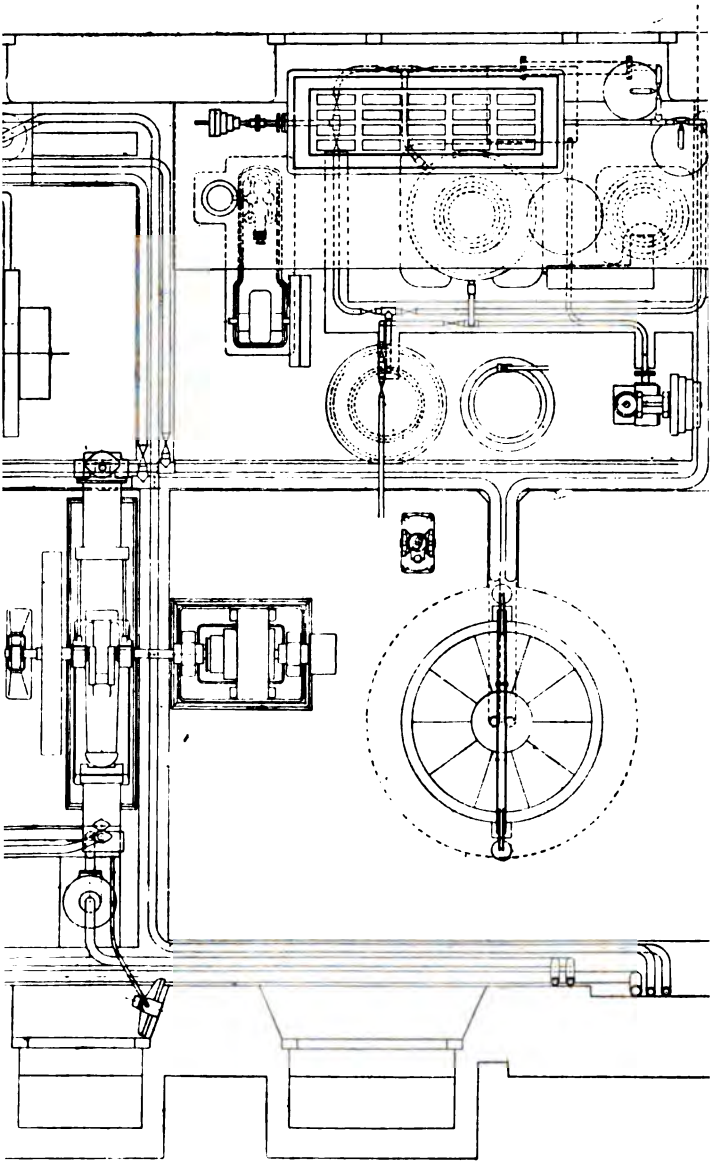

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Plate XXV.

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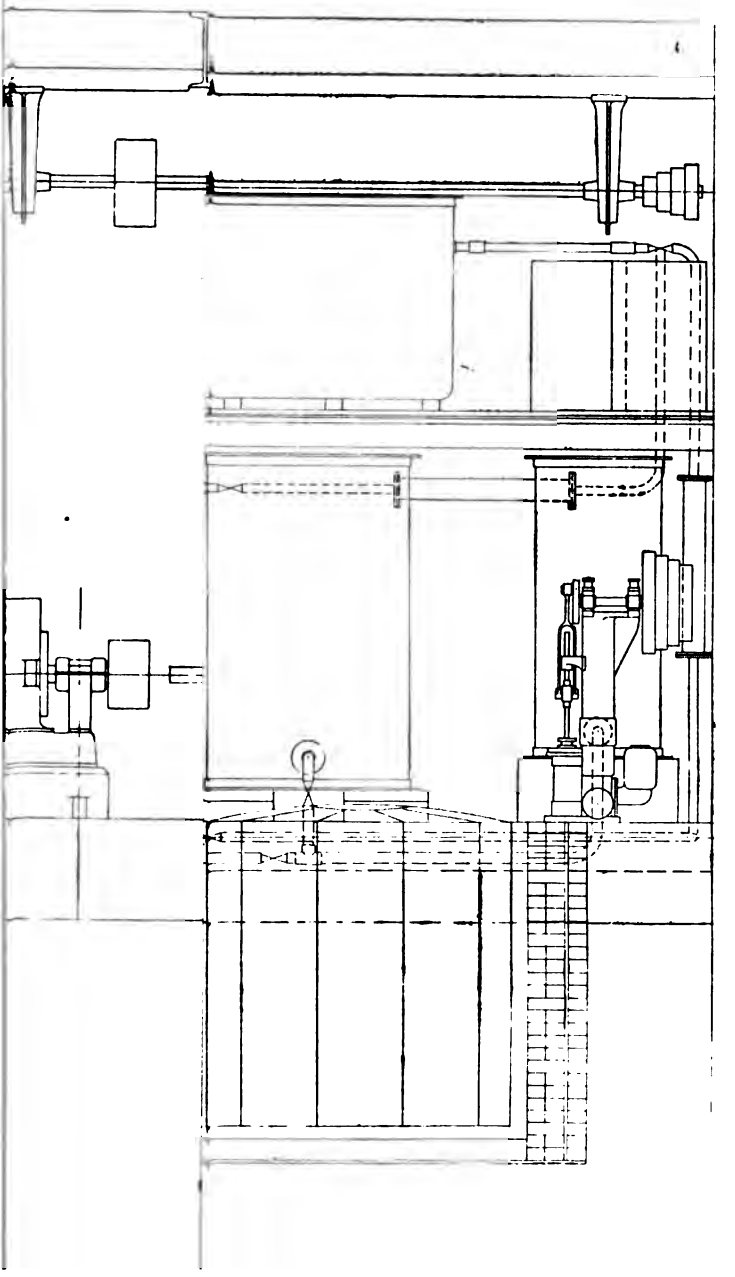

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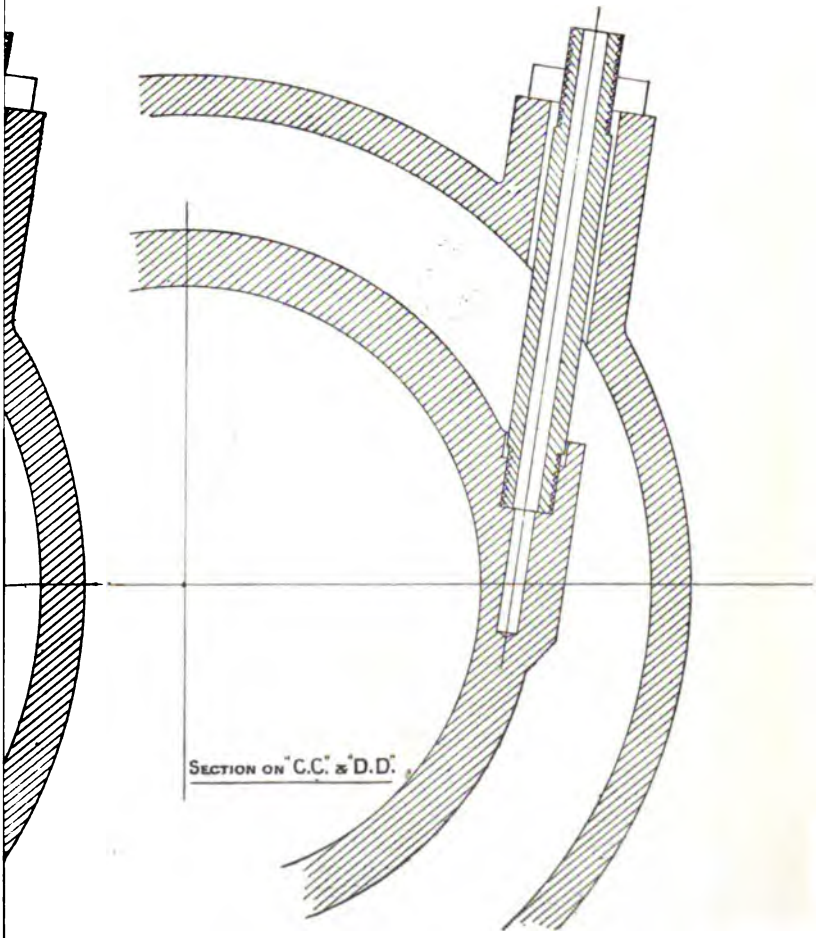

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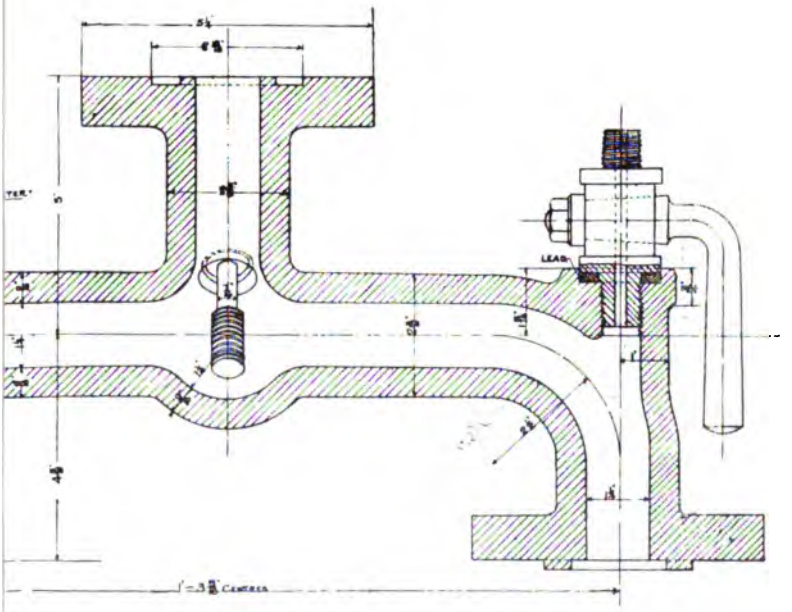

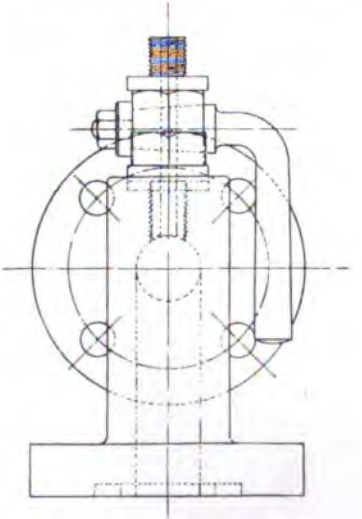

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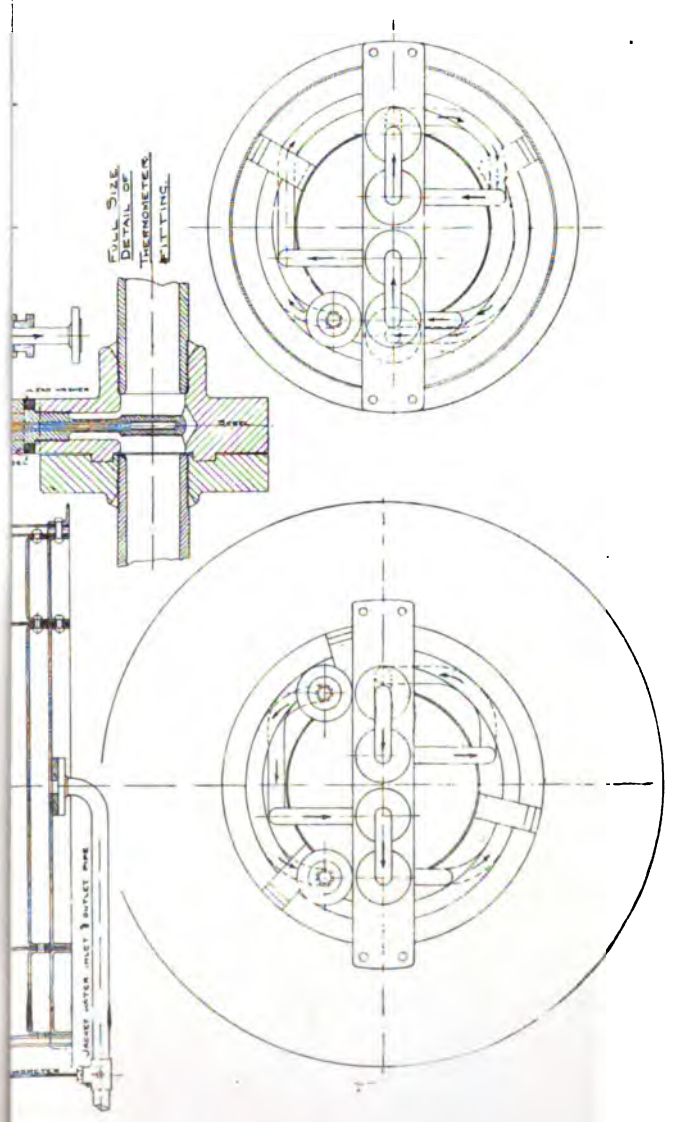

onia Refrigerating Plant.

Plate XXX.

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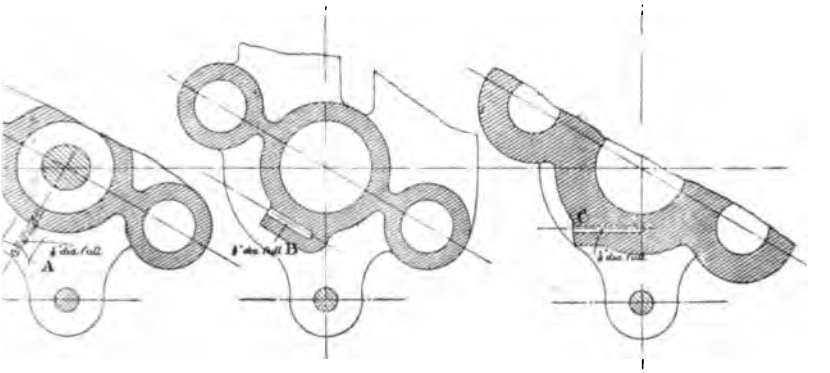

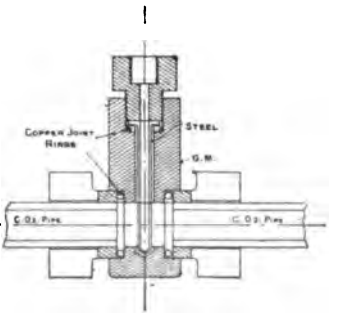

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Plate XXXI.

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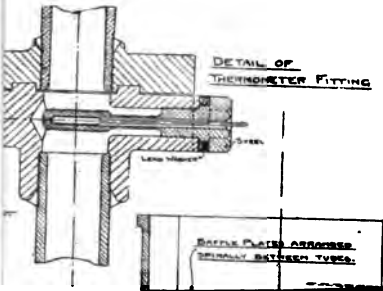

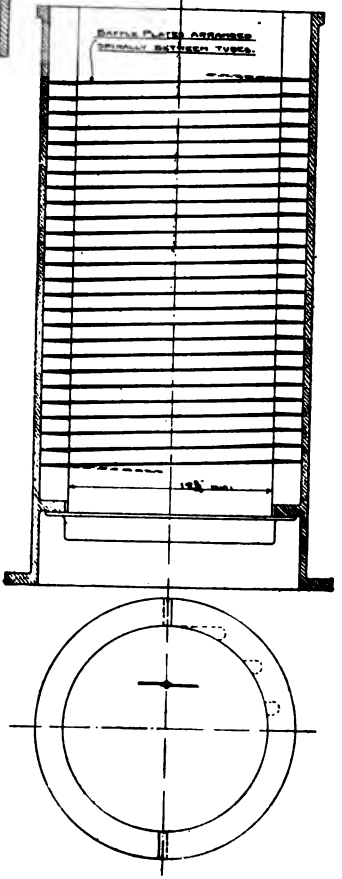

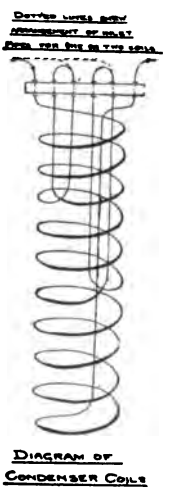

DIAGRAM OF
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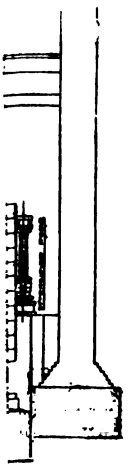
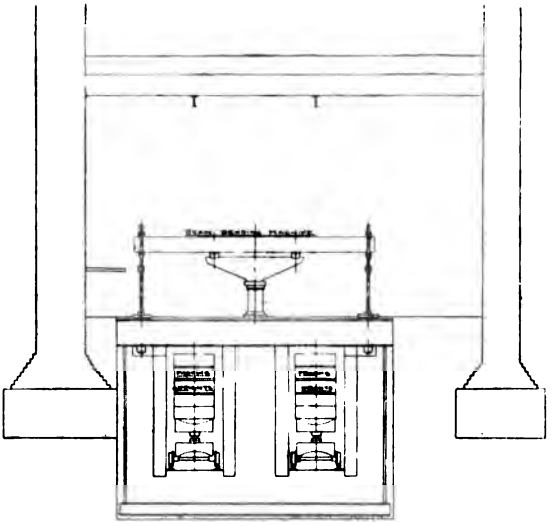
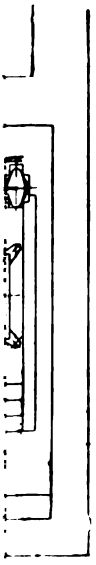
Fig. 2.







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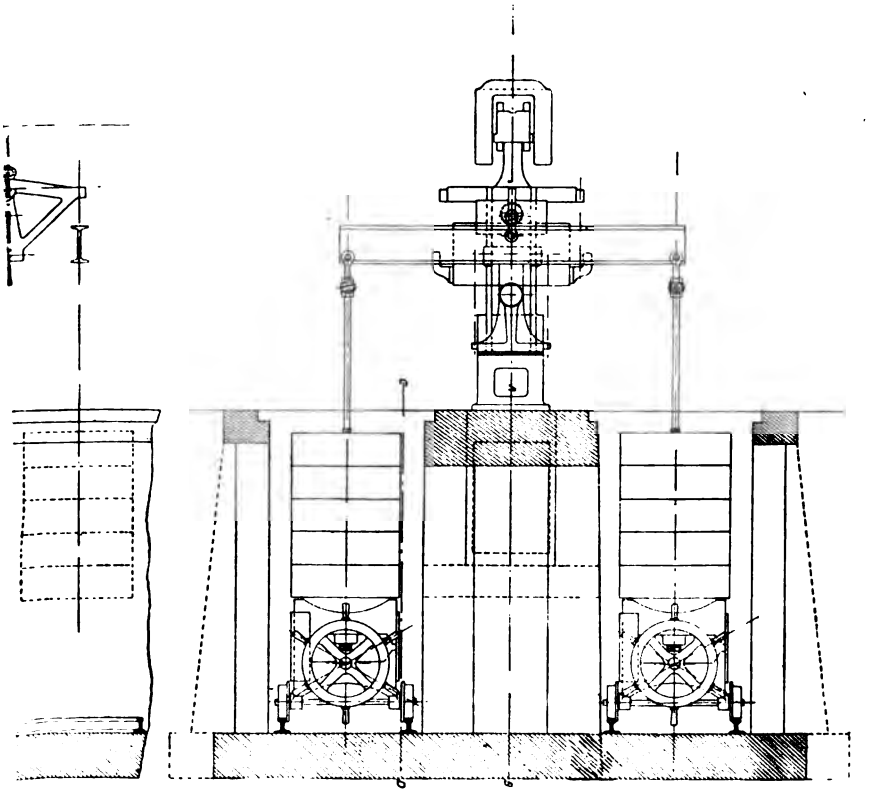

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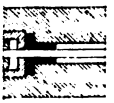

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Plate XXXV.

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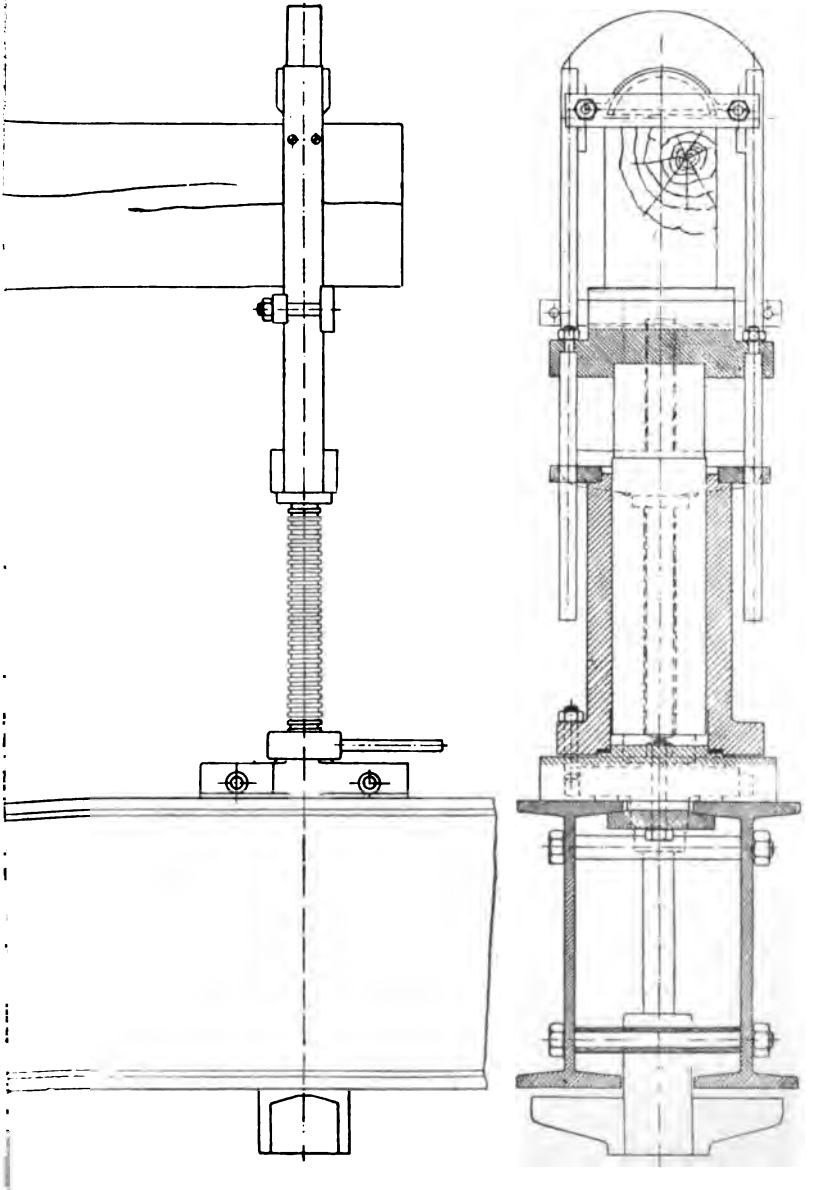

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REPORT ON EXPERIMENTS

WITH

RAPID CUTTING STEEL TOOLS,

made at the Manchester Municipal School of Technology, under the auspices of a Joint Committee of Members of the Manchester Association of Engineers and of Members of the School of Technology Sub-Committee together with Dr. J. T. Nicolson (Professor of Mechanical Engineering at the above School).

PREPARED BY

DR. J. T. NICOLSON,

Approved by the Joint Committee on October 19th, 1903, read before the Association on October 24th, 1903, and discussed on November 7th, 1903.

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REPORT ON EXPERIMENTS WITH RAPID CUTTING STEEL TOOLS.

PART 1.—INTRODUCTORY.

These experiments were undertaken to test the capabilities of some of the high speed tool steels that have recently been developed.

They were made under the direction of a Joint Committee of members of the Council of the Manchester Association of Engineers, and of members of the Engineering Sub-Committee of the Manchester Municipal School of Technology, together with Dr. J. T. Nicolson, *Professor of Engineering in that school.*

The names of the members of this Joint Committee are as follows:—

Manchester Association of Engineers.	Manchester Municipal School of Technology.
E. G. Constantine (*President*),	Sir James Hoy, LL.D.
Daniel Adamson (*Hon. Sec.*),	Joseph Nasmith (*Chairman*),
H. N. Bickerton,	Charles Day,
Geo. Daniels.	Dr. Dearden,
	F. W. Follows,
	Francis Godlee,
	E. G. Hiller,
	Ivan Levinstein,
	Councillor Wilson,
	Prof. A. Schuster.

Dr. J. T. Nicolson (*Reporter*).

Early in January, 1902, Mr. Charles Day, at that time a member of Council of the Manchester Association of Engineers, suggested to the President of the Association, Mr. E. G. Constantine, the advisability of appointing a committee to

investigate the new rapid cutting tool steels that were being brought to the notice of engineers.

On January 9th the Council of the Association considered the matter, and Mr. Henry Webb, a Past President, suggested that the Municipal School of Technology would be a very suitable place for the proposed experiments to be carried on.

On January 29th, 1902, the President and Mr. Day met the Chairman of the Technical Instruction Committee, Alderman Hoy, Mr. Reynolds, Principal of the School of Technology, and two members of the Technical Instruction Committee, and they generally approved of the suggestion that their committee should combine with the Association of Engineers in this matter. The four members of the Council of the Association named above were appointed on February 26th and March 26th to represent the Association on a joint committee to carry out the intended experiments, in accordance with arrangements made at a preliminary meeting at the School of Technology, on March 3rd, 1902.

ARRANGEMENTS FOR THE EXPERIMENTS.

On March 3rd the school section of the joint committee agreed to find the lathe and turner, the power, the instruments to be used and the observers; and this was confirmed at a meeting of the general committee later. The Association members promised to provide the material to be operated upon, and the tool steel makers were to be asked to supply the tools to be experimented with.

Dr. Nicolson, Professor of Mechanical Engineering at the Municipal School of Technology, undertook to be responsible for the accuracy of the observations and records of the experiments, and to draw up a report upon the same. It was decided that this report should be signed by the following members of the joint committee:—

Mr. Joseph Nasmith as Chairman of the Engineering Sub-Committee and Chairman of the Joint Committee;

Mr. E. G. Constantine as President of the Manchester Association of Engineers;

Mr. Daniel Adamson as Honorary Secretary of the Association Section of the Committee; and

Dr. J. T. Nicolson as Reporter to the Joint Committee.

It was also resolved that this report should be first issued to the public through the agency of the Manchester Association of Engineers.

All the tool steel making firms whose names were familiar to members of the committee at that time as having specialised a steel for rapid cutting were written to and invited to participate in the trials, under conditions then issued, by sending tools and having representatives present during the experiments with their own tools. The names of the tool steel makers who accepted this invitation and sent tools for the experiments will be found in the tables giving the results. Applications received later from other steel making firms wishing to participate had to be refused to avoid prolonging the trials unduly, it being felt that a sufficient number had entered to render the experiments of value for the guidance of tool steel users as to the possibilities of the new steels.

It was decided to confine the experiments to lathe tools and to record the weight of material removed, area of surface machined, cutting speed, depth of cut, traverse per revolution, duration of trial, condition of tool at end of trial, and power absorbed during the trial. The angles of the tools, how hardened and ground, the height of the cutting edge in relation to centre of lathe were also to be noted.

After careful consideration it was decided to leave the shape of the tools to the makers rather than specify the angles to which the tools were to be ground. The reason for this decision

being that the intention of the experiments was to bring out the best results obtainable rather than to ascertain which was the best brand under equal competitive conditions. This could be ascertained by tool steel users for themselves.

On April 23rd, 1902, the following circular letter and schedule of conditions of the proposed experiments was issued to the steel makers.

MUNICIPAL SCHOOL OF TECHNOLOGY,
Sackville Street,
Manchester, *23rd April, 1902.*

Dear Sirs,

A Joint Committee of members of the Manchester Association of Engineers and of the Engineering Sectional Committee of the Municipal School of Technology, Manchester, together with Dr. Nicolson, Professor of Engineering in the said school, has been formed to carry out, under certain conditions, a series of experiments to determine the maximum capabilities of the tool steels that have been recently introduced.

The advantage of obtaining this information by the method proposed is that the full benefit to be derived from the experiments upon the quality and behaviour of the new tool steels can be obtained by users sooner than by waiting for each user to carry out his own experiments, in his own works, where perhaps he may have neither the time nor the facilities for such a thorough investigation as the resources of the above Joint Committee will provide.

Several of the members of this committee are commercially and all are scientifically interested in obtaining the best possible results from tool steel, and they feel confident that the intended experiments will be to the mutual advantage of themselves, of other users, and of the tool steel makers.

The Joint Committee therefore enclose for your perusal a copy of the conditions of the proposed experiments, and will be glad to learn whether you are inclined to assist them by the loan of tools, and further, by having a representative present at the experiments carried out with the same. If so, they will be glad to have the accompanying form filled up and returned with your reply.

The experiments will, in the first instance, be confined to tool steels made in this country.

A reply addressed to me by Monday morning next, April 28th, will much oblige.

I am, Yours faithfully,
J. H. REYNOLDS,
Principal.

Schedule of conditions of proposed experiments with steel for turning tools.

1. It is proposed in the first instance to test turning tools on bars of forged steel and cast iron, each of three degrees of hardness.

2. The relative hardness of the materials operated upon will be ascertained either by analysis or by drilling.

3. The experiments will be made at the Municipal School of Technology, in Sackville street, Manchester, and at least two members of the Joint Committees (one of whom will be Dr. Nicolson, who makes himself personally responsible for the accuracy of the actual records), will be present at every trial.

4. It is suggested that each tool steel maker shall submit as a maximum twelve tools, each 1½in. square by 12 inches long, two for each specimen to be operated upon. These tools should be delivered to the Committee forged and ground ready for use, and it should be stated whether or not the tools can be forged and tempered under ordinary workshop conditions.

5. The Committee will be glad to have suggestions from the tool steel makers as to the most suitable depth of cut, traverse and cutting speed to be taken with each of the tools to obtain the best possible results measured (1) by the maximum quantity of material removed per unit of time, and (2) by the maximum area of surface machined when taking a cut $\frac{3}{16}$in. deep, also per unit of time. They will be glad also to learn from tool steel makers the maximum speeds at which they recommend their tools to be worked, (3) with a cut of $\frac{3}{16} \times \frac{1}{16}$in. traverse, and (4) with a cut of $\frac{1}{16}$in. $\times$ $\frac{1}{16}$in. traverse. Each test will be conducted for a period of twenty minutes. (A list accompanies these conditions which should be filled up by the tool steel maker).

6. Notice will be given to each tool steel maker when the experiments with his steel will be carried out, and he can then, if he so desires, arrange for a representative to be present.

7. Records will be taken of the weight of material removed, also of the area of the surface machined, as well as of the speed, cut and traverse, also of the duration of test, the condition of the tool at the end of the test, and lastly of the power absorbed during the test. The size of the section of tool steel used, the angles of the tool, how hardened and ground, and the height of the cutting edge in relation to the

centres of the lathe will be duly noted. It will also be noted whether the tool is removing the skin of the material, or whether this has been done already at a previous operation.

8. The results of all the trials together with full particulars of the materials operated upon, and also the names of the makers of each tool will be made public in the first instance through the agency of the Manchester Association of Engineers.

9. All the tools submitted should be clearly marked to indicate the purpose for which they are intended, and they should also be marked with a consecutive number which will be supplied

List of Particulars to be filled in by firms intending to participate in the proposed "Tool Steel Experiments" for a test of twenty minutes duration.

Name of Firm ...

Address .....

.....

Place where the tool steel is made .....

List of the Speeds, &c., recommended by Tool Steel Makers.

Material to be operated upon.		Forged Steel			Cast Iron		
		Soft	Mild	Hard	Soft	Medium	Hard
The cutting speed recommended in ft. per min.	1						
	2						
	3						
	4						
Depth of cut ..	1						
Traverse	1						
	2						

1. To remove maximum weight per minute.
2. To machine maximum area of surface per minute with $\frac{3}{16}$in. cut.
3. Maximum speed recommended for given cut of $\frac{3}{16}$in. × $\frac{1}{16}$in. traverse.
4. Maximum speed recommended for given cut of $\frac{1}{16}$in. × $\frac{1}{16}$in. traverse.

To be returned with the reply.

On April 28th, 1902, it was decided that the following should be the percentage of carbon in the steels to be operated upon :—

Soft Steel	0·2 %.
Medium Steel	0·3 %.
Hard Steel	0·5 %.

A preliminary trial was made on that date with a 10in. lathe obtained from Messrs. Hetherington & Sons; but it was found that the capacity of the lathe was not great enough for the size of bars, both as to diameter and length, which it would be necessary to operate upon in order to have sufficient surface for the speeds and lengths of trial intended.

This lathe withstood successfully some very heavy and rapid cutting, and the thanks of the committee were tendered to Messrs. Hetherington for the loan of their lathe in the preliminary trials.

On June 2nd, 1902, the Committee accepted the offer of Messrs. Sir W. G. Armstrong, Whitworth & Co., Limited, to place a lathe of greater capacity at their disposal for the purpose of the experiments; as also the further offer to supply free of charge the three bars of steel and the three bars of cast iron required for the tests. The thanks of the Joint Committee are due to Messrs. Armstrong, Whitworth & Co., for their liberality in this matter.

The careful consideration of the Committee was given to the question of the duration of the trials, and to the depths of cut and widths of traverse feed to be taken upon each; having in view the information obtained from tool makers in response to the circular letter of the 23rd April.

Having regard to the answers obtained to query (1) of paragraph (5) of the schedule of conditions, it was decided to make the cut $\frac{3}{8}$in., and the traverse $\frac{1}{8}$in. for all tools. In reference to (2), with a given cut of $\frac{3}{16}$in., a traverse feed of $\frac{1}{8}$in. was agreed upon. It being left to the tool steel makers to

determine the speeds at which they would run their tools in the endeavour to obtain the highest cutting speed, consistent with non-failure of the tool during a trial of specified duration.

In the other two series of trials, queries (3) and (4), it was also a question of determining the highest speed of cutting which could be maintained during a given time at the cuts and traverses specified, viz: $\frac{3}{16}$ by $\frac{1}{16}$, and $\frac{1}{16}$ by $\frac{1}{16}$.

The durations decided upon for the various trials were as follows:—

Duration of trials upon	Soft Steel	-	20	minutes.
,, ,,	Medium Steel		30	,,
,, ,,	Hard ,,	-	30	,,
,, ,,	Soft Cast-iron		30	,,
,, ,,	Medium ,,	-	30	,,
,, ,,	Hard ,,	-	60	,, for $\frac{3}{16}$ by $\frac{1}{8}$ cuts.
,, ,,	Hard ,,	-	30	,, for all others.

As an amendment to the first instructions issued to the tool makers it was agreed to allow them to submit 24 tools, instead of 12; one for each of the four trials on the six specimens to be operated upon, or, in case they should prefer to use one tool for two tests, as originally intended, it was agreed that such tool might be re-forged or re-ground at the School in the presence of the Committee. The tools were all $1\frac{1}{4}$in. square.

Soon after the commencement of the trials competitors were allowed to increase their cutting speeds during a trial by an amount not exceeding $12\frac{1}{2}\%$ of the speed at starting.

The soft steel trials lasted from October 27th, 1902, to December 12th, 1902.

The medium cast iron trials from December 19th, 1902, to January 22nd, 1903.

The medium steel trials from January 23rd, 1903, to February 6th, 1903.

The hard cast iron trials from February 18th, 1903, to February 27th, 1903.

The hard steel trials lasted from March 4th, 1903, to March 18th, 1903.

The soft cast iron trials lasted from March 18th, 1903, to March 27th, 1903.

From July 9th to July 27th, 1903, a series of "*endurance*" tests were carried out. These trials were to be of two hours duration, and were made with one tool of each maker upon both soft steel and medium cast iron (of which materials sufficient remained for these further experiments). The tools were chosen from those already used, and were re-forged at the School to the makers' instructions, and afterwards ground to a shape common to all.

Trials were also made, for the sake of comparision, with tools of ordinary water-hardened steel, and ordinary Mushet steel.

On July 27th, 1903, the official trials were concluded.

A number of unofficial experiments, with transmission and absorption dynamometers constructed at the School, were made during the continuance of the main trials, to determine the efficiency of the drive, and the actual force on the cutting tool at different speeds and areas of cut. The nature and results of these tests are given in Parts V. and VIII.

The thanks of the Joint Committee are due to the following: The Principal; Mr. Dempster Smith, Demonstrator of Mechanical Engineering; Mr. George Anderson, Draughtsman: Mr. J. T. Hodgson, Mechanical Superintendent; and Mr. C. Coups, Turner, for assistance in carrying out the trials, and working out the results.

Part II.—INFORMATION WITH REGARD TO SPEEDS AND CUTS SUPPLIED TO THE COMMITTEE BY TOOL MAKERS.

As already described in Part I., a schedule of particulars (there reproduced) was issued to the tool steel makers for the

purpose of obtaining from them the following information with regard to the carrying out of the proposed trials.

(1). As to what depth of cut, traverse per revolution, and speed of cutting they would recommend for removing the maximum weight of material per minute.

(2). As to the traverse and cutting speed they would propose for machining the maximum area of surface per minute with a $\frac{3}{16}$in. cut.

(3). As to the maximum speed recommended for a given cut of $\frac{3}{16}$in. $\times$ $\frac{1}{16}$in. traverse; and

(4). The maximum speed recommended for a given cut of $\frac{1}{16}$in. $\times$ $\frac{1}{16}$in. traverse.

All the above data were to be given for six different materials viz: soft, mild, and hard forged steel, and soft, medium, and hard cast iron.

The data asked for were duly received and carefully considered. The conclusions already narrated in the introductory part of this report, as to the cuts and traverses to be adopted, were arrived at in consequence, being embodied in the regulations established for the conduct of the trials, and recorded in the minutes of the meetings of the Joint Committee.

Part III.—PROCEDURE IN MAKING THE TESTS.

The mode of procedure in carrying out the trials was as follows:—

In all cases the skin was first removed and the bar was machined over at the same traverse as that to be used in the test so that sufficient area of surface was available for the trial at the speed of cutting and duration proposed.

A sketch was then made of the bar, and its diameters accurately measured in two or more places in the part to be operated on. The distance from the end of the bar at which the cut was to commence was measured.

The tool, having been measured, was placed in position to the instructions of the steel maker's representative; its position relatively to the centre of the work and its overhang from the slide rest being noted.

The lathe having meanwhile been started, observations of the surface speed of the bar were taken, and the motor speed adjusted until the desired cutting speed of the job was arrived at.

The self-acting traverse was then put in gear and the tool set up until the point of the tool just scraped the bottom of the groove left by the last turning. This tool slide screw was fitted with a disc having its edges marked with a zero mark and with the four depths of cut usually employed, viz., $\frac{1}{16}$in., $\frac{1}{8}$in., $\frac{3}{16}$in., $\frac{3}{8}$in.; and any one of those marks could be set opposite to an index mark on the tool rest. When the tool was set up to the work as just described, care was taken that the disc was at zero.

The self-acting gear was then thrown out, the slide screw turned back a little and the saddle moved to the right by hand sufficiently to clear.

The tool slide screw was then used to set the tool forward until the disc showed the required cut opposite the index mark. The tool was then ready for starting the test.

The self-acting traverse was put into gear, and as the tool entered upon the cut the time was exactly noted, and another observer noted the reading of a revolution counter worked from a crank on the lathe spindle.

This counter, as also the voltmeter and ammeter connected with the motor brushes, were read every two minutes throughout the trial; frequent observations of the motor speed were also made with a Horn's Tachograph, which read accurately.

If the tool kept a reasonably good point and appeared to be cutting all right, it was not withdrawn until the expiration of

the agreed upon time, such as 20, 30 or 60 minutes, even if it had ceased to take the full cut to which it was set.

After withdrawal of the tool the lathe was run for a little while at the average speed of the trial, to enable the electrical horse-power exerted by the motor, in running it light, to be observed. This was always necessary, as the bars were differently supported with wood chocks in different trials, and the friction horse-power running light varied considerably.

All cuttings were collected and weighed; and the distance traversed and diameter of the bar at bottom of cut were measured.

Part IV.—DESCRIPTION OF LATHE LOANED BY SIR W. G. ARMSTRONG, WHITWORTH & CO. LD., FOR THESE TRIALS; AND OF THE METHOD OF DRIVING THE SAME.

The lathe was a 15in. centre screw cutting lathe, taking in a length of 9ft. 6in. between centres. For these experiments it was fitted with 18in. centre headstocks; the fast headstock having both double and treble back gears: the gear-ratio being 14·9 to 1, and 42·5 to 1. This headstock was specially fitted with a three-step cone suitable for a 6in. belt. The bed was replaned, and a new compound slide rest was fitted. The general arrangement drawing of the lathe is reproduced in the accompanying Plates I. and Ia.

The lathe was driven by a direct-current shunt-wound Schuckert motor of 120EHP, supplied with current from the 3-wire power leads of the school at a voltage of 220. A large air-cooled rheostat of 88 steps with a maximum resistance of 3·2 ohms was connected in the main circuit between line and brushes; and with this apparatus the speed of the motor could be varied between 150 and 800revs. per minute at no load on the lathe, and from 60 to 800revs. per minute with heavy cuts by simply moving the rheostat handle shown in Plate II.

The lathe was driven through two intermediate countershafts. The motor pulley 30in. diameter drove on to a 36in. diameter pulley by a 10in. belt. From the first countershaft another 10in. belt drove from a 36in. pulley thereon to a 30in. pulley on the second countershaft. On the latter three pulleys were set opposite the three cone pulleys on the lathe.

Diameter of pulleys:—

Countershaft 32·7in. 27·85in. and 23·68in.
Lathe Cone 15·67in. 19·58in. ,, 23·58in.

Thus the speed ratio of lathe spindle to motor shaft were as follows:—

Particulars of Drive		Spindle to Motor.	Surface speed of Bar, 5ft. circumference, with motor running at		
Gear	Cone Pulley	Speed ratio	300 revs. per min.	200 revs. per min.	100 revs. per min.
Single	Small	2·075	3130	2086	1043
do.	Middle	1·413	2120	1414	707
do.	Large	1·0	1500	1000	500
Double	Small	·14	209	138	69
do.	Middle	·0954	143	96	48
do.	Large	·0674	101	68	34
Treble	Small	·0490	7·35	49	24·5
do.	Middle	·0334	50 2	33·4	16·7
do.	Large	·0235	35·3	23·6	11·8

Any required cutting speed between 12 and 200 feet per minute could thus be obtained, with the back gears in use, upon a bar of five feet circumference, with great convenience.

Part V.—DESCRIPTION OF THE APPARATUS USED AND THE METHODS ADOPTED FOR MEASURING THE FORCE REQUIRED IN CUTTING.

At every trial, observations of the current supplied and of the brush-volts of the motor were made every two minutes during the cut; when the tool had been withdrawn, and the motor speed thereafter re-adjusted to its average during the test, two readings were taken of the same quantities with the lathe running light. The difference between the electrical

horse-power of the motor when driving the cutting tool and when only driving the lathe and intermediate gearing gives the net horse-power required for cutting, and if this be reduced to foot-pounds per minute and divided by the cutting speed, we obtain the force exerted in cutting, in pounds.

The correctness of the figure so deduced depends upon the accuracy of the assumption which underlies this method—that the waste horse-power of the drive remains the same when the lathe is cutting as when it is running light (with the forging in place). This waste horse-power consists of—firstly, lost electrical energy in the motor, due to ohmic resistances in armature and field, eddy currents in armature-cores and pole-pieces, and hysteresis in the armature-cores; secondly, mechanical frictions in the motor, the countershafts, and the lathe, work lost by the bending and unbending, and the slip and creep of the belts.

A considerable number of experiments were made to verify the truth of this assumption. A Prony brake was mounted upon the forging in the way shown in Plate II., and could be clamped so as to offer as great a resistance to turning as the tool-point on its heaviest cut, the whole being cooled by water. The torque exerted by the brake was observed by noting readings on the scale-beam of a weighing machine, on whose platform the thrust of the brake-lever was taken, at a known distance from the lathe-centre.

Advantage was also taken of the horizontal belt between the two countershafts to install a belt dynamometer of the kind first used by Von Hefner Alteneck. Its nature is readily understood from the figure Plate II. The horse-power transmitted is known from the value of the weight which must be placed in the scale-pan (S) in order to maintain the dynamometer frame in its zero position (as indicated by pointer and scale R), and from the observed speed of the belt (B B). Thus the gross electrical

horse-power of the motor (G), the horse-power transmitted through the dynamometer (T), and the horse-power delivered upon the Prony brake (N), were separately measured.

Experiments were made with the lathe running under all the six possible modes of driving it through its two back gears—from no load to that at which the belt slipped, the motor speed being kept constant throughout.

Runs were also made at constant load under three different motor speeds with the double back gear only.

The results of these trials were plotted with the transmitted (or dynamometer) horse-power (T); the net horse-power (or that absorbed by the Prony brake) (N); and the lost horse-power between motor and brake (L) as ordinates, upon a base of gross electrical horse-power (G) absorbed by the motor; and from the diagrams so obtained the following formulæ connecting the lost horse-power (L) the net or brake horse-power at the lathe (N) and the gross EHP (G) were deduced:—

$$L = 10 + \tfrac{1}{5}N \quad \ldots \ldots \ldots \ldots \ldots \quad (1)$$

$$N = 0{\cdot}9G - 9 \quad \ldots \ldots \ldots \ldots \ldots \quad (2)$$

This applies to a constant motor speed of 250revs. per minute, and for all gears and cone steps.

By plotting all the light run horse-powers (L_0) of the main trials as ordinates on a base of motor speeds, the expression :—

$$L_0 = 0{\cdot}0875R + 0{\cdot}6 \quad \ldots \ldots \ldots \ldots \quad (3)$$

was obtained, giving the connection between total lost horse-power and motor speed (R in revolutions per minute), with the lathe running light.

Thus a general expression for the lost power taking account both of motor speed and load is

$$L = 0{\cdot}0875R + 0{\cdot}6 + \tfrac{1}{5}N \quad \ldots \ldots \ldots \quad (4)$$

$$\text{or } L = 0{\cdot}0875R + 0{\cdot}1G - 0{\cdot}4 \quad \ldots \ldots \quad (5)$$

Expression (1) shows that the lost horse-power increases somewhat with the load; and does not remain constant as required by the above mentioned assumption.

It was also found that the friction or lost horse-power was much affected by the condition of the lathe at the commencement of the experiment.

If newly started up, with lubricants cold and viscous, the lost power would be from $\frac{1}{2}$ to $1\frac{1}{2}$HP more than when the lathe had become thoroughly warmed up, as after a lengthened run.

On this ground a careful re-examination of all the log sheets and results was made; and corrections were introduced in the horse-power readings, which are recorded in the Tables XIII. to XVIII. under columns 6, to allow for the condition of the lathe as to temperature.

These corrections in the net horse-power from which the cutting forces are deduced, are especially important at the light cuts, and although it is believed that the cutting forces and stresses, as deduced, are not far from the truth, those given for the lighter cuts ought not to be regarded with the same degree of confidence which the figures for the heavy cuts may claim.

The nature of the results obtained with regard to the values of the cutting stress for different materials, and the variation of the same with the speed of cutting, is discussed in Part VIII. of this report.

Part VI.—RESULTS OF EXPERIMENTS.

The results obtained with the eight different brands of steel experimented upon, as regards area machined and weight removed at the various speeds and cuts, are recorded in the annexed Tables I., II., III., IV., V. and VI.; one for each of the six materials operated upon.

In each of these Tables there are four groups of tests, one for each of the four different cuts, viz:—$\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse; $\frac{2}{16}$in. cut by $\frac{1}{16}$in. traverse; $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse; and $\frac{2}{8}$in. cut by $\frac{1}{8}$in. traverse.

The 1st column gives the names of the tool steel makers in alphabetical order; the 2nd the name of brand of tool steel; the 3rd column gives the number of the trial. Columns 4, 5 and 6 give the speeds, cuts and traverses at which the trials were intended to be carried out; whilst 7, 8 and 9 give the actual speeds, cuts and traverses at which the tests took place, as found by measurement and observation. By the cutting speed is meant the speed in feet per minute of the cylindrical surface, obtained by taking the mean diameter of the work before and after machining. The depth of cut was of course half the difference between these two diameters, which were measured by micrometer calipers in from one to three places. The traverse was the distance along the job from the start to the finish of the cut, divided by the number of revolutions of the lathe spindle made during the cut. Column 10 gives the area of section of cut, being the product of cut and traverse. Column 11 gives the duration of the trial in minutes; Columns 12 and 13 give the area machined during the trial and the area machined per minute in square feet, whilst columns 14 and 15 give the total weight of cuttings removed during the run and the weight removed per minute. These results were obtained by the collection and weighing of the cuttings. Column 16 gives the reason for withdrawal of the tool. Column 17 gives the number representing the relative condition of the cutting edge of the tool after the experiment; a lower number indicating superiority in this respect.

Table VIa. gives the results of the trials made with ordinary water hardened and ordinary Mushet steel tools upon soft steel, and upon soft and medium cast iron.

These trials show that 31 feet per minute with a cut of $\frac{1}{16}$in. by $\frac{1}{16}$in. is the superior limit of speed for ordinary water hardened steel operating upon Whitworth fluid pressed soft steel; whilst an ordinary Mushet tool can run at over 60 feet per minute, with a $\frac{1}{16}$in. by $\frac{1}{16}$in. cut upon the same material. With the new steel this cut was taken at 150 feet per minute.

Experiment No. 26, entered in this table, was a heavy cut $\frac{3}{8}$in. deep by $\frac{3}{8}$in. traverse, to test the driving power of the belts. The cutting stress deduced from this trial is 128 tons per square inch, which figure further verifies the linear law of variation of cutting force with area of cut for steel announced in Part VIII.

With regard to the trials on medium cast iron, it appears that 25 feet per minute is too high a speed with $\frac{1}{16}$in. by $\frac{1}{16}$in. cuts, 17 feet is too high with $\frac{3}{16}$in. by $\frac{1}{16}$in. cuts, and 15 feet is too high with $\frac{3}{16}$in. by $\frac{1}{8}$in. cuts for ordinary water hardened tool steels; whereas the new steels ran nearly 60 feet, 49 feet and 33 feet per minute as a maximum on these three cuts respectively. An ordinary Mushet ran for over 20 minutes at 23·6 feet per minute on a $\frac{1}{16}$in. by $\frac{1}{16}$in. cut; whilst it failed at 19 feet per minute on a $\frac{3}{16}$in. by $\frac{1}{16}$in. cut, and at 15 feet per minute on a $\frac{3}{16}$in. by $\frac{1}{8}$in. cut on this material.

In the case of soft cast iron, 22 feet per minute was too high a speed for water hardened steel taking a $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse as against 72 feet per minute with the new steels; whilst an ordinary Mushet lasted over half an hour at 31·6 feet per minute with the same cut upon the same material.

All these results are shown on Plates III. and IV., where the speeds obtained upon the various cuts are plotted.

The next tables, numbered VII. to XII. give the particulars of the tool angles and position of tools when cutting. Column 1 gives the steel maker's name, and column 2 the number of the experiment.

Columns 3, 4, 5, 6, 7 and 8 give the particulars required for reproducing the tools as they were used in these trials. Columns 3 and 4 give the front top rake and front clearance respectively; the former being the angle between a line in the top surface and another line parallel to the bottom of the tool, both taken through its point, and the latter the angle between two lines through the same point, one vertical and the other down the front of the tool.

In order to measure the angles in columns 5 and 6 we take a vertical plane (C D Fig. 1) parallel to the axis of the work in the lathe, through that point of the cutting edge of the tool where it is intersected by the uncut surface of the work, and observe the angles made by the traces of this plane upon the top and side surfaces of the tool, with horizontal and vertical lines respectively.

Columns 7 and 8 are self-explanatory; column 9 gives the angle subtended by the heights in column 7 at the centre of the work.

In columns 10 and 11 are tabulated the values of what may be called the *true cutting angles*. They are taken in the vertical plane containing the direction of motion of the shaving whilst in contact with the top of the tool, and are measured both before and after the tool has made the cut. The direction of motion of the shaving over the tool point, column 12, can be very approximately inferred from the appearance of the tool; as in many cases the shaving rubs away a portion of the top surface of the tool, leaving the cutting edge intact, and indicating the direction of flow of shaving. The true cutting angle is thus rendered more acute than when the tool began the cut. In such cases it was observed that the shaving was curled to a smaller radius as the test progressed. When the direction of motion of the shaving differed considerably from that of the tool axis, this (so-called) true cutting angle of

the tool differs materially from the front cutting angle. In most cases, however, there is but little difference.

Strictly, these angles ought to be taken relatively to a line tangent to the work at the tool point, but for simplicity, they were measured relatively to a vertical angle; and this amounts to neglecting the angle (β) which the height of tool point above centre subtends at the axis of the work.

Column 18 records *the cutting arc*, or length of the tool point which was operating upon the work. This practically is the same width as the shaving.

Column 14 gives the total weight removed during the trial by each tool, and is inserted for the purpose of rendering it easier to compare the performance of the tool with its angles,

Fig. 1 gives a plan and sections of the tool whereby the above descriptions of its angles may be more readily apprehended.

The plan view of each of the tools and the cut upon which it was used in the trials is reproduced in Appendix II., in the series of Plates XIII. to XVI., so that the influence of form upon performance may be investigated.

In Tables XIII. to XVIII. are recorded the results obtained with regard to gross, tare, and net horse-power observed in the trials, and to the force acting upon the tool point when cutting; each table having reference to one of the six materials operated upon.

The columns 1 and 2 give the toolmaker's name and the number of the experiment. Column 3 gives the gross electrical horse-power absorbed by the motor when the tool was cutting; column 4 gives the frictional horse-power or that observed when the lathe was running light at the same speed as when cutting. Column 5 gives the difference between 3 and 4; and is the net horse-power required for cutting, as determined from these electrical readings. Column 6 gives the net horse-power as in column 5, but corrected by allowance

being made for extra friction due to the lathe having been run cold in some experiments and not in others. (*v.* Part V., page 243) Column 7 gives the average speed of cutting; and from columns 7 and 6, column 8 is deduced; giving the calculated cutting force upon the point of the tool. Column 9 gives the product of the cut and traverse; or the area of the cut in square inches. Column 10 gives the motor speed and column 11 the nature of the gear in use during the run. Below columns 8 and 9 are

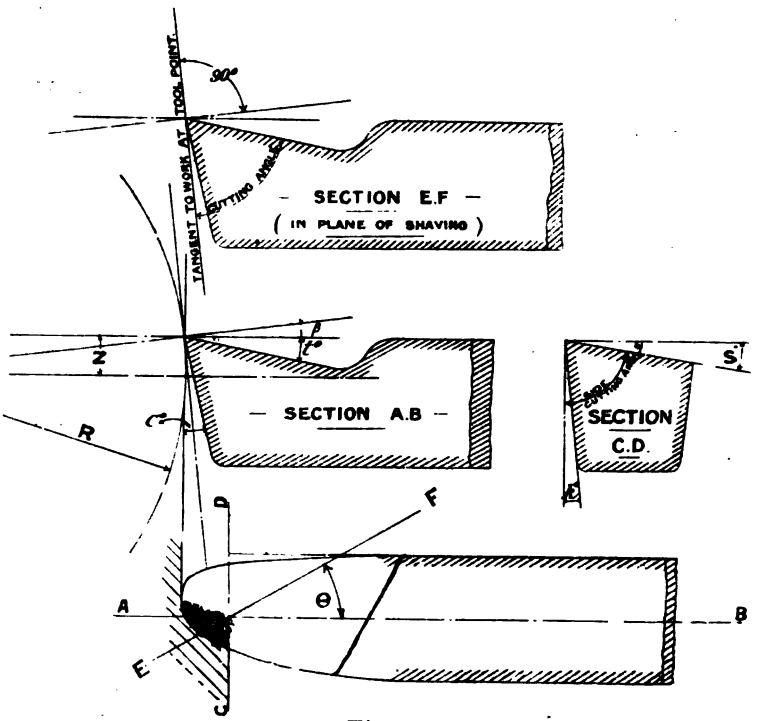


Fig. 1.

given the average cutting stress in tons per square inch for each group of tests. They are obtained by dividing the average cutting force in tons by the average area of section of cut in square inches.

Part VII.—RELATION BETWEEN ALLOWABLE CUTTING SPEED AND AREA OF CUT WITH DIFFERENT MATERIALS.

Plates III. and IV. depict the variation of the speeds of cutting which obtained with the six kinds of material operated upon, as depending upon the area of the cut. Plate III. is for the soft, medium and hard steel, and Plate IV. for the same varieties of cast iron. In each case the full line curves give the maximum speed at which any tool ran the full time at the given cut; whilst the dotted lined curves indicate the *average speeds* at which the given area of cut was taken by all the tools tested, whether any of them failed to complete the trial or not.

The following simple approximate expressions indicate the relations depicted in the curves, between speed of cutting and area of cut.

Let v = cutting speed in feet per minute, and a = area of cut in square inches (product of cut and traverse).

Then:—For soft steel $$v = \frac{1{\cdot}95}{a + 0{\cdot}011} + 15$$

For medium steel $$v = \frac{1{\cdot}85}{a + 0{\cdot}016} + 6$$

For hard steel $$v = \frac{1{\cdot}08}{a + 0{\cdot}016} + 4$$

For cast iron the results are not of so simple a character; but the following expressions give speeds which may probably be attained as a maximum:—

For soft cast iron $$v = \frac{8{\cdot}10}{a + 0{\cdot}025} + 8$$

For medium cast iron $$v = \frac{1{\cdot}65}{a + 0{\cdot}08} + 7$$

For hard cast iron $$v = \frac{1{\cdot}8}{a + 0{\cdot}035} + 5{\cdot}5$$

Taking in all six cases those trials only in which the tool ran for the whole time specified and removed the greatest weight, the following Table (XIX) has been prepared showing also the speeds attained for the various cuts employed.

Table XIX.

Soft Steel. (Whitworth fluid-pressed)

Intended Cut and Traverse	Actual Area of Cut	Max. Speed of Non-fails	Weight Removed
Inches.	Sq. Inches.	Feet per minute.	Lbs. per min.
$\frac{1}{16} \times \frac{1}{16}$	·00325	149·2	1·72
$\frac{3}{16} \times \frac{1}{16}$	·0106	111·0	4·137
$\frac{3}{16} \times \frac{1}{8}$	·0215	74·0	5·28
$\frac{3}{8} \times \frac{1}{8}$	·0484	50·7	7·5
Medium Steel (fluid-pressed).			
$\frac{1}{16} \times \frac{1}{16}$	·0039	105·2	1·5
$\frac{3}{16} \times \frac{1}{16}$	·0114	80	3·17
$\frac{3}{16} \times \frac{1}{8}$	·02275	51·4	3·88
$\frac{3}{8} \times \frac{1}{8}$	·0425	38·6	5·56
Hard Steel (fluid-pressed).			
$\frac{1}{16} \times \frac{1}{16}$	·00397	52·5	0·725
$\frac{3}{16} \times \frac{1}{16}$	·0124	41·20	1·708
$\frac{3}{16} \times \frac{1}{8}$	·0219	30·8	2·3
$\frac{3}{8} \times \frac{1}{8}$	·0452	20·25	3·1
Soft Cast-Iron.			
$\frac{1}{16} \times \frac{1}{16}$	·0039	109	1·3
$\frac{3}{16} \times \frac{1}{16}$	·0124	99·5	3·602
$\frac{3}{16} \times \frac{1}{8}$	·0214	66·2	4·383
$\frac{3}{8} \times \frac{1}{8}$	·0459	55·5	7·458
Medium Cast-Iron.			
$\frac{1}{16} \times \frac{1}{16}$	·00331	59·7	0·69
$\frac{3}{16} \times \frac{1}{16}$	·0115	49·0	1·78
$\frac{3}{16} \times \frac{1}{8}$	·0227	33·1	2·28
$\frac{3}{8} \times \frac{1}{8}$	·0446	24·35	3·32
Hard Cast-Iron.			
$\frac{1}{16} \times \frac{1}{16}$	·00375	38·5	0·483
$\frac{3}{16} \times \frac{1}{16}$	·01173	31·9	1·183
$\frac{3}{16} \times \frac{1}{8}$	·02112	24·7	1·621
$\frac{3}{8} \times \frac{1}{8}$	·0459	22	3·2

These figures for weights removed, are plotted and curves drawn through them in Plate V.

This plate shows how very greatly the weight removed increases as the cuts become heavier. The weight removed on the heavy cuts is from seven to four times what can be removed on the light cuts; the former figure applying to the soft, the latter to the hard materials.

It further appears that heavy cuts will be much more economical in power; for the waste work is a much larger proportion of the whole work required at light cuts than at heavy cuts. It is probably this fact which has given rise to the commonly accepted opinion that the cutting stress increases with the speed (as instanced by the objections of workmen to increase cutting speeds on account of the anticipated springing of the work), contrary to the results of these trials, which rather show the reverse to be the case. In soft steel, for example, the average horse-power required for actual cutting at $\frac{1}{16}$in. by $\frac{1}{16}$in. was 8, whilst at $\frac{3}{8}$in. by $\frac{1}{8}$in. it was 15. The friction horse-power of lathe and countershaft was about 2½HP. The weight removed was about 105lbs. and 445lbs. per hour at the light and heavy cuts respectively, so that the weight removed per gross horse-power hour was 19·1lbs. for the light and 25·8lbs. for the heavy cut. Neglecting frictional loss these figures would have been 35 and 29 respectively.

In the case of cast-iron, the gain in power at the heavier cuts is still more conspicuous. Here the effective horse-power was 1·7 and 5·5 at the $\frac{1}{16}$ by $\frac{1}{16}$ and $\frac{3}{8}$ by $\frac{1}{8}$ cuts respectively; the waste horse-power being about 2. The weights removed were 42lbs. and 198lbs. per hour (as seen in Plate V.), and the weights per HP-hour were therefore: 11·35lbs. at the light cut, and 26·5lbs. at the heavy cut.

These results are of general application, and show that not merely can more material be removed in a given time with a

heavy cut at its proper speed than with a light cut at the highest speed which the new steels can take, but that this can be done at a smaller expenditure of gross power per ton of shavings removed.

In Plate VI. are seen curves co-ordinating the greatest area of surface machined by any of the tools in each series of trials with the six materials. They are plotted on a base of area of cut.

Part VIII.—RESULTS AS TO THE VARIATION OF CUTTING FORCE WITH AREA OF CUT AND OF CUTTING STRESS WITH SPEED.

The force exerted by the tool in cutting was determined, as explained in Part V., by deducting an assumed lost horse-power from the gross electrical horse-power observed on the trial, the difference being the net or effective cutting horse-power; this, being reduced to foot-lbs. per minute, and divided by the speed of cutting, gives the force exerted. The figures so obtained have been plotted as ordinates, upon a base of area of cut, in Plate VII.

For steel they show that the cutting force is simply proportional to the area of cut, and that this force has the following approximate values:—

For soft steel (fluid compressed)	115	tons	per sq. in.
,, medium ,, ,,	108	,,	,,
,, hard ,, ,,	150	,,	,,

It must be remembered, however, that the speeds at the lighter cuts were from two to four times as great as for the heavier ones; and that, as the cutting force for any given section of cut may vary with the speed, the relation between the cutting force and the area cut *at any one given speed* may differ from the above linear law.

In order to test this point, a series of trials were made upon medium steel by means of a lathe-tool dynamometer (constructed for actually observing a force acting upon the tool),

at a constant speed of cutting of about 85 feet per minute. Several different cuts were taken at each of two traverses, viz.: $\frac{1}{16}$in., $\frac{1}{8}$in., $\frac{1}{4}$in., and $\frac{3}{8}$in. cuts at $\frac{1}{16}$in. traverse; and $\frac{1}{16}$in., $\frac{1}{8}$in., $\frac{3}{16}$in., $\frac{1}{4}$in., and $\frac{3}{8}$in. cuts at $\frac{1}{8}$in. traverse.

The results of these experiments are shown on Plate VIII. The lines are slightly curved upwards instead of being true straight lines passing through the zero of co-ordinates; but this is probably due to the tools becoming blunter as the trials proceeded; for they were made in the order of time enumerated above; the lightest first. It will be noticed that when the tool had failed with a cut $\frac{3}{8}$in. by $\frac{1}{8}$in. and had been reground the same (intended) cut was made with a much lower observed cutting force. The conclusion from these trials is that the cutting force is proportional to the product of cut and traverse and equals about 95 tons per square inch for the medium steel.

The other full line curve is of a similar character and gives for the same material a cutting stress of 115 tons per square inch. The difference between these two values of the cutting stress tends to show that fine traverses take more power than coarse ones for the same area of cut. The dotted curves in the plate give the value of the cutting force calculated from the electrical observations made during the same trials.

On Plate VII. have also been plotted the values of the cutting force obtained in the experiments of Prof. R. H. Smith, which are graphed in his work, "Cutting Tools."

In the endeavour to find the law according to which the cutting stress varies with the speed, the average value of the cutting force for each group of eight tests (made with eight different steels upon a given material with approximately the same feed and cut and the same speeds) was divided by the mean of the areas cut; and the average cutting stresses so

obtained, twenty-four in number, were plotted as ordinates on a base of speed, as shown by Plate IX.

The uncertainty in the determination of the values of the cutting stresses by means of the volt- and am-meter readings, especially at the lighter cuts (*i.e.*, the higher speeds) already referred to in Part V., is made more clearly manifest by this diagram.

If the values for the very lightest cuts ($\frac{1}{16}$ by $\frac{1}{16}$) be entirely ignored, then in the case of steel the cutting stress would appear to diminish somewhat as the speed increases. In the case of cast-iron nothing can be inferred but a certain approximation to constancy of the cutting stress and an independence of speed. The speed variation in the latter case is of a much more limited range, however, than for the steels.

On the whole, the verdict appears to be that the cutting stress has not been shown by these experiments to vary very much with speed.

For cast-iron this stress may be specified as follows :—

For soft cast-iron	51	tons per square inch.
For medium cast-iron ...	84	,, ,,
For hard cast-iron	82	,, ,,

A few experiments were made with the lathe-tool dynamometer in regard to this question of variation of cutting force with speed. The first series were made with a constant cut of $\frac{3}{16}$in. by $\frac{1}{8}$in. at speeds varying from 80 to 90 feet per minute upon medium steel. The results are plotted at *a a* on Plate IX. Unfortunately they are not so reliable as could be wished, as some of the observers (students) were not very good.

A second series (made on October 18th, 1908) is of a more trustworthy character. They were made upon medium cast-iron, with a cut $\frac{3}{16}$in. by $\frac{1}{16}$in. at speeds from 10 to 60 feet per minute. These trials are also plotted on Plate IX., a fair curve

(*b b*) being drawn through them. They show a fairly regular diminution of the cutting stress as the speed of cutting increases.

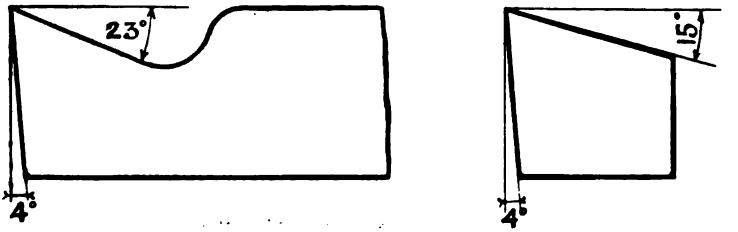
Part IX.—RESULTS OF THE TRIALS MADE TO TEST ENDURANCE OF THE NEW STEELS UPON A LENGTHENED RUN, WITH AN UNIFORM SHAPE OF TOOL.

The object of this series of trials was to ascertain whether lengthened runs could be made with the new steels at speeds approaching those adopted for the shorter runs of the earlier trials without serious deterioration of the cutting edge. They were intended to be of two hours' duration upon both soft steel and medium cast-iron. The tools were chosen from those already used—one from those supplied by each maker; were reforged at the opposite end to that used in the main trials, tempered in the School to the makers' instructions, and ground to a shape common to all. The shape and angles adopted are shown in Figs. 2 and 3; and the tools were so placed that the cutting edge was on the level of the centre of the work. Trials were also made with ordinary Mushet and ordinary water-hardened steel tools for comparison with the above.

The results of all these trials are given in Tables XX. and XXI.

These trials show that a speed of 90 feet per minute may be maintained for a considerable period, with a $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse, upon material similar to the fluid-pressed soft steel operated upon, as only 3 out of 7 tools failed to fulfil the expectations of the Committee. They also show that the new steels will cut more than twice as fast as ordinary Mushet steel, and more than four times as fast as ordinary water-hardened steel.

With regard to the endurance trials on medium cast-iron, three out of the thirteen tools tried ran for an hour, or longer, at 34 feet per minute with a $\frac{3}{16}$in. by $\frac{1}{16}$in. cut; but no tool completed the intended run of two hours' duration.



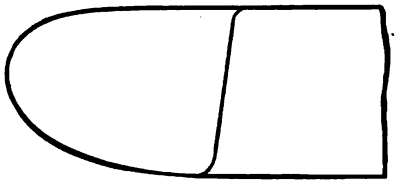
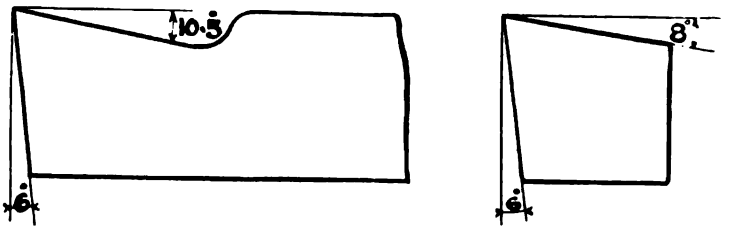


Fig. 2.



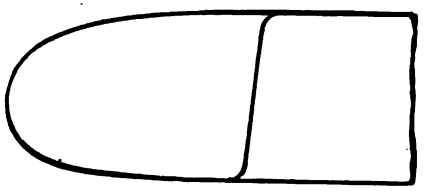


Fig. 3.

An ordinary Mushet tool ran for an hour on this material at a speed of 19½ feet per minute, whilst ordinary water-hardened tools failed in from 4 to 9 minutes at 12 feet per minute.

Part X.—RESULTS OF THE PHYSICAL, MECHANICAL, AND CHEMICAL TESTS OF THE MATERIALS OPERATED UPON.

1. *Physical.*—The *density*, or weight in lbs. per cubic foot, of these materials was determined in the Physical Laboratory

of the School, by Mr. Arthur Adamson, Lecturer in Physics, to whom the thanks of the Committee are due. Two specimens were cut from each of the six bars, and the average of each pair is given in the annexed Table XXII.

Table XXII.—Table of Densities.

In lbs. per cubic foot.

	Determined by A. A.
Soft Steel	490·8
Medium Steel..	490·4
Hard Steel	490·0
Soft Cast Iron	443·4
Medium Cast Iron	447·4
Hard Cast Iron	454·2

The hardness was determined by drilling a piece cut from each sample with a standard drill loaded with a constant weight, and rotated at a constant speed in all trials. As is not unusual, a diagram-apparatus was employed to give a written automatic record of the result of each trial. Vertical motion of the pencil (on the diagrams here re-produced) Plate X. represents number of revolutions of the drill, whilst horizontal motion represents distance drilled. Thus the tangent of the angle of slope of the line is a measure of (this kind of) hardness. It may be enumerated, also, as the number of revolutions of drill required to penetrate each one-hundredth of an inch of depth.

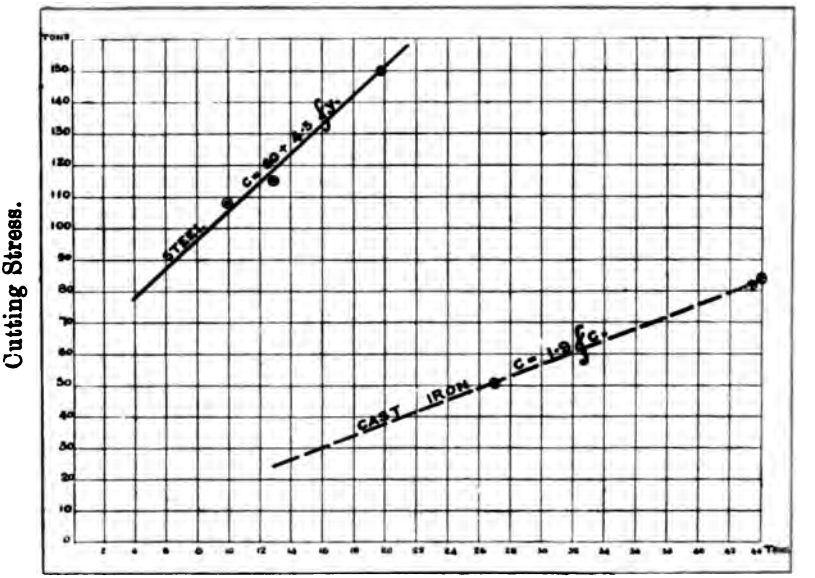
The effect of temper and sharpness of the drill are taken account of by drilling the standard sample of material at frequent intervals.

The tests are re-produced in the annexed Table XXIII; and the diagrams have been traced off the original cards, and are given in Plate X.

2. ***Mechanical Tests.***—Three specimens each for both tension and compression tests as to elastic limit, ultimate strength, and modulus of elasticity, were cut from each of the six materials operated upon. These tests were made in the Materials Testing Laboratory of the School by Mr. W. C. Popplewell, M.Sc., to whom the thanks of the Committee are due for this part of the work.

The results are given in Table XXIV.

Fig. 4.



Crushing Stress and Yield Stress.

DIAGRAM OF CUTTING STRESS AND ELASTIC PROPERTIES.

In Fig. 4 are shown the relations existing between the cutting stress of the different materials used and the elastic properties of the materials as determined in the testing machine. With regard to the particular figures to be chosen in Table XXIV. against which to plot these stresses, it would obviously be useless to take the maximum or breaking stresses for the steel specimens (given in column 8) and expect them to agree

with the cutting stresses. These breaking stresses are referred to the original area of the bar, the actual ultimate tenacity of the material being much higher, and the proportion in which it is greater being different for the different materials depending upon their percentage reduction of area. It is more reasonable to expect an agreement between the yield-point stresses and the stresses required in cutting, for in both cases it is the failure of the material by shearing which is the material factor. Those who have watched the behaviour of a polished flat bar at the yield-point will be aware of this; for they will have seen the ripple-marks which appear upon the surface and run over it from end to end, making an angle of 45 degrees with the direction of the pull. This is not to be taken as meaning that the ultimate failure of the material when it breaks does not also take place by shearing; on this point, the views expressed by Mr. J. J. Guest in his great paper on that question are no doubt correct; but the phenomenon is then so complicated by the question of contraction and ductility that no close measure of the rigidity of the material can be taken. The shaving on the other hand fails by shearing off successive little strips at angles depending on the properties of the material, but not, so far as had yet been shown, upon the tool angles.

If, then, the cutting stresses for steel as given in Part VIII. of the report—which on their face seemed to vary erratically—are plotted against the yield-point stresses recorded in column 7 of Table XXIV., the upper graphs of the annexed diagram are obtained; and most satisfactory agreement is found between the two sets of figures.

Expressed in linear form we may write:—

$$c = 60 + 4{\cdot}5 f_y,$$

where c and f_y are the cutting and yield stresses respectively in tons per square inch.

In cast-iron, on the other hand, the cutting and crushing stresses are plotted against each other, and here again a surprisingly satisfactory result is found. It is, of course, well known that cast-iron test-pieces fail in compression tests by shearing across surfaces inclined at high angles to the direction of thrust.

A linear expression connecting the two stresses is:—

$$c = 1{\cdot}9 f_c,$$

where c and f_c are the cutting and crushing stresses respectively in tons per square inch; and the graph appears to pass through the origin.

If these are the true relations, they ought to be of some importance, as anyone would, by using them, be able to foretell the cutting stress of a material by merely determining the yield-point stress, or the crushing stress of specimens made from it in the case of steel and cast-iron respectively. In any case the agreement of these mechanical constants of the materials with the average values of the cutting stresses given in the report is a strong confirmation of the correctness of the latter, as determined in the manner explained in Part V.

3. *Chemical Tests.*—The chemical analysis of each sample was performed in the Metallurgical Laboratory of the School by Mr. E. L. Rhead, Lecturer in Metallurgy, to whom the thanks of the Committee are due. The samples analysed were taken from that end of the bar in each case which was at the bottom of the mould; the bars being cast vertically.

In Plate XI. curves have been plotted co-ordinating the highest cutting speeds obtained with the three varieties of steel, and the carbon contents. A regular variation of the two quantities is shown.

The results are contained in the following Table XXV.:—

Table XXV.—Table of Chemical Composition of Materials.

Substance	PERCENTAGES		
	Soft Steel	Medium Steel	Hard Steel
Carbon	0·198	0·275	0·514
Silicon	0·055	0·086	0·111
Manganese	0·605	0·650	0·792
Sulphur	0·026	0·037	0·033
Phosphorus	0·035	0·043	0·037

Substance	PERCENTAGES		
	Soft Cast Iron	Medium Cast Iron	Hard Cast Iron
Combined Carbon	0·459	0·585	1·15
Graphite	2·603	2·720	1·875
Total Carbon	3·062	3·305	3·025
Silicon	3·010	1·703	1·789
Manganese	1·180	0·588	0·348
Sulphur	0·031	0·061	0·1614
Phosphorus	0·773	0·526	0·732

The Report is signed by the following on behalf of the Joint Committee.

JOSEPH NASMITH,
Chairman of Joint Committee.

E. G. CONSTANTINE,
President of Manchester Association of Engineers.

DANIEL ADAMSON,
Honorary Secretary.

J. T. NICOLSON,
Reporter.

October 19th, 1903.

Three appendices are attached to the report:—

Appendix I. gives the printed instructions furnished by the tool steel makers to their customers for the forging and hardening of their steels.

Appendix II. contains in Plates XIII. to XVI. exact reproductions of the shapes in plan of the points of all the tools employed, numbered consecutively. The depth and area of cut taken by each tool when on trial is also shown, together with the angle at which the cutting crossed the tool point.

Appendix III. gives a *prècis* of the German experiments made upon tool steels in 1901, with tables containing the results obtained by their best tools, on cast iron, mild steel and cast steel. The figures have been taken from the Report published by the German Committee in the *Zeitschrift des Vereins Deutscher Ingenieure* for the 28th September, 1901, and converted into English units.

APPENDIX I.

SIR W. G. ARMSTRONG, WHITWORTH & CO.

Instructions for Working the Steels.

"A.W." High Speed Tool Steel.

Directions for Forging and Hardening.

Heat slowly and thoroughly to a **cherry red,** and forge in the ordinary way. When forged to the required shape, the **point** should be heated to a **white melting heat,** and allowed to soak at this heat until it commences to run, then place in an **air blast to cool,** and afterwards grind on a **wet stone.**

NOTE.—No water is required for hardening this steel. These directions should be carefully adhered to.

JOHN BROWN & COMPANY LIMITED, Atlas Works, Sheffield.

Instructions for Treating.

"Atlas Self-Hard Steel."

Before it is worked, the steel should be soaked well in a Smith's fire without any blast. After this the blast should be applied until the steel is at a good white heat. It is then ready for smithing, and to give the best result the tool should be finished at this heat. After the smithing of the tool is finished, re-heat again to the very highest possible heat without burning, although it is no detriment to the tool if the point should be slightly fused in the process, and then allow to cool gradually. The tool is then ready for use without any further treatment than grinding.

This steel is suitable for any class of tool, and for working upon any class and temper of material at any speed up to the highest attainable.

To be treated as ordinary tool steel when grinding; plenty of water being kept on the stone.

SAMUEL BUCKLEY, St. Paul's Square, Birmingham.

Directions for Working.

Styrian High-Speed Tool Steel,

Marked **Bohler * Rapid Selfhard.**

For roughing and finishing hard materials, including chilled castings, at high-speed with heavy cuts and coarse feed. May also be used for milling cutters, taps, reamers, etc.

For Cutting Off.

To avoid cracks, etc., heat the bar slowly and carefully. Nick while hot and break off required lengths when cold.

For Forging.

Heat to a good light yellow, taking care to heat often enough to prevent the heat running down to a cherry red.

For Hardening.

After the forging is done re-heat to a soft bright yellow heat (mellow lemon colour) and cool in cold blast or in oil.

To Anneal.

Cover with powdered charcoal and anneal in hermetically sealed boxes for about four to six hours (according to size) at a temperature of 1,800 degrees F. to 1,900 degrees F. (1,000 degrees C.) Allow the boxes to cool slowly.

CHARLES CAMMELL & CO. LIMITED.

Instructions for Treating.

Special Self-Hardening Tool Steel.

When it is required to run the lathe at an ordinary speed:—Smith the tool in the same way as an ordinary turning tool, and heat the nose say 2in. to a white heat. Allow the tool to cool in the open air, grind, and it is ready for use.

When it is required to run the lathe faster than ordinary speed:—Smith the tool in the same way as an ordinary turning tool, and heat the nose say 2in. to a white heat. Allow the tool to cool in a dry place. When cold, grind, and let the cutting end of tool down on a hot bar to a dark blue colour and keep until the colour has quite disappeared, then allow the tool to cool slowly, and it is ready for use.

Note.—The tool may be heated to the white heat in a Smith's hearth, if care is taken not to use too fierce a blast.

THOS. FIRTH & SONS, LIMITED, Sheffield.

"N. F. K. Speedicut."

Instructions for Forging and Grinding.

Forging.

Forge as you would any ordinary tool steel but not until the portion to be forged has attained a uniform heat all through.

On no account continue forging below a red heat or minute cracks will develop.

Allow no water to touch the steel while forging.

When forged to shape heat the tool end to a white heat, remove it smartly from the fire to anvil and, with light, sharp, successive blows, hammer all the cutting part until it reaches a full red colour—then cool out in air blast. The hammering improves the steel and secures a fine finish with little trouble. It also saves time as a good smith will make this high heat his last forging heat; nothing, however, but hand hammering must then be done.

No tempering is required.

Grinding.

Grind either quite dry or with a surplus of water on a stone or emery wheel—an intermittent or faulty supply of water must not be used.

SAMUEL OSBORN & CO., Sheffield.

Instructions for Working.

Mushet High-Speed Steel.

When forged, the cutting end of the tool should be **reheated to a white heat,** and then immediately **blown cold.**

Whilst hot this steel must be kept from water.

SEEBOHM & DIECKSTAHL Limited, Dannemora Steel Works, Sheffield.

Instructions for Treatment of both Qualities of Tools for the Tool Steel Tests.

"New Capital" High-Speed Steel.

To Harden in Strong Cold Blast.

Heat slowly, forge at an ordinary heat, then bring about 1in. to 1½in. of point **slowly** to a **white heat** and cool instantly in a strong cold blast until quite cold.

Oil Hardening.

When a cold blast is not available, or for **hard materials,** heat point **slowly** to **white heat,** and plunge the whole tool into **oil.**

VICKERS, SONS, & MAXIM LIMITED, River Don Works, Sheffield.

Instructions for Working.

Vickers' "High Speed" Steel.

Forging.

Heat the bar slowly to a **yellow heat**; forge at this heat without allowing the tool to cool lower than a **bright red.** It is better to place the tool in the fire several times rather than to forge at a heat higher than yellow or lower than bright red. The tool may be put in the fire again at once for hardening, but the best results are got by rough-grinding before hardening, in which case the tool should be put with its nose in lime or ashes to cool.

Hardening.

Heat the tool slowly up to a **bright red heat,** then rapidly to a **brilliant yellow,** and for machining ordinary material place on the ground (free from damp) to cool; if for use on particularly hard metals it may be found advantageous to place it in a strong blast of air to cool. When cold, the tool, if only rough-ground, should be finished ground before tempering.

Grinding.

All grinding should be done on a stone with plenty of water on it.

Tempering.

The tool, if larger than 1½ inches square, may be reduced to the required temper, to suit the material operated upon, by placing the shank of the tool in a hot fire with the blast off. The colour will be seen on the face of the tool, and for most purposes a bright blue will be found a satisfactory temper. After obtaining the required temper put the tool in a dry place to cool. As a rule it is not necessary to temper tools less than 1½ inches square.

APPENDIX III.

THE GERMAN EXPERIMENTS ON RAPID-CUTTING STEEL.

These trials were carried out by a Committee of the "Verein Deutscher Ingenieure" (Union of German Engineers) selected from the Berlin section, together with the managers of some of the larger engineering workshops in Berlin.

Although seven of the largest workshops in Berlin were available for the experiments, the steels could not be tested therein to the limit of their power on account of (1) shortage of material under normal working conditions; (2) lack of sufficient power, or (3) insufficient speed upon the lathes.

Thereupon the Niles Machine Tool Co. placed a 36in. centres lathe 10ft. long between centres, and the German General Electric Co. a motor, at the disposal of the Committee. With this combination a long series of trials was carried out in the Niles Works.

The object of the trials was to determine, keeping in view the durability or life of the tools:—

(1) What maximum surface could be machined in unit of time with a given cut of $\frac{3}{16}$in., the traverse and speed being left open.

(2) What weight of cuttings could be removed per unit of time with the greatest possible depth of cut, the traverse and speed being again left open.

The materials operated upon were grey cast-iron, cast-steel, and forged or rolled Siemens-Martin steel of various strengths. The duration of each trial was to be two hours.

The tool steel was supplied by the three firms:

Bergische Stahl Industrie, of Remschied.
Gebrüder Böhler & Co., of Vienna and Berlin.
Poldi-Hütte, ,, ,,

The first firm supplied their ordinary air-hardened steel, *Mark L.*

The second supplied two sorts; *Titan-Boreas* and *Rapid.*

The third firm supplied their self hardening steel, mark *Diamant 000*, as also their special tool steel, marked *Schnell-dreher.*

About 250 trials were made; and in the following tables selections of the best of the results are given in English units.

Table A.—Cast Iron.

Brand of Steel used.	Trial No.	Duration. mins.	Cut. ins.	Traverse. ins.	Area of Cut. sq. in.	Cutting Speed. feet per min.	Weight removed per min. lbs.	Surface Machined per min. sq. ft.	Skin or not.
Bo. R. ..	425	59 ➤	·1456	·1850	·0269	72·9	7·39	1·107	No
P.D. ..	515	61 ➤	·1870	·1692	·0316	50·3	5·21	·775	No
Bo. R. ..	424	120 ➤	·520	·1634	·0850	47·3	14·43	·710	No
Bo. R. ..	409	120 ➤	·579	·096	·0556	37·4	6·25	·291	No
Bg. St. I.	611	120 ➤	·559	·063	·0352	37·4	4·61	·226	No
P.D. .. .	514	120 ➤	·520	·1417	·0737	35·4	7·39	·387	No
P.D.	275	103 ➤	·300	·1437	·0431	35·4	5·65	·484	No
Bg. St. I.	633	30	·516	·1613	·0832	33·5	10·45	·538	No
Bg. St. I.	326	148 ➤	·396	·0867	·0343	33·5	4·31	·237	No
P.D.	273	190	·4375	·1043	·0456	27·6	5·74	·366	Yes

Table B.—Siemens-Martin Steel.

Brand of Steel used.	Trial No.	Duration in mins.	Cut. Ins.	Traverse. Ins.	Area of Cut. Sq. ins.	Speed of Cutting, feet per min.	Weight removed per min. Lbs.	Surface machined per min. sq. ft.	Skin or not.	Quality of of Steel.
P. S.	261	20	·091	·0670	·0061	194	3·33	0·950	No.	
P. S.	263	63 ➤	·170	·0670	·0114	136	4·84	·678	No.	
Bo. R.	136	95	·181	·0906	·0164	126	5·92	·808	No.	
Bo. R.	432	22	·223	·1025	·0228	91	6·16	·686	No.	A*
Bo. R.	433	30	·260	·1140	·0296	72	7·50	·783	No.	A
Bo. R.	106	155	·232	·0394	·0091	69	2·33	·259	No.	
Bo. R.	434	60 ➤	·260	·0945	·0245	65	3·22	·497	No.	A
Bo. R.	430	113	·197	·1160	·0228	45·2	3·21	·399	No.	B
Bo. R.	103	135	·343	·0630	·0216	41·3	2·82	·216	No.	
P. D.	219	140	·232	·1045	·0244	35·5	2·64	·313	No.	
Bo. R.	429	120 ➤	·492	·0945	·0464	31·6	4·71	·237	No.	B
Bo.T.B.	412	120 ➤	·473	·0513	·0243	17·4	1·43	·075	No.	C
Bo. R.	413	250 ➤	·256	·0513	·0131	35·5	1·1	·162	No.	C

* See Table D below.

Table C.—Cast Steel.

Brand of Steel used.	Trial No.	Duration in mins.	Cut. Ins.	Traverse. Ins.	Area of Cut. Sq. ins.	Cutting Speed, feet per min.	Weight removed per min. Lbs.	Surface machined per min. sq. ft.	Skin or not.
Bo. R.	420	120 ➤	·2265	·067	·01517	47·3	2·457	·28	No.
Bo. R.	419	120 ➤	·2166	·067	·01450	33·5	1·45	·189	No.
P. D.	271	100 ➤	·590	·0275	·01622	31·55	2·346	·097	Skin
Bg. St. I.	624	120 ➤	·394	·0512	·02018	26·6	2·149	·1185	No.
Bg. St. I.	328	133 ➤	·2205	·086	·01896	21·7	2·777	·151	No.
Bg. St. I.	623	120 ➤	·610	·0512	·03122	19·71	2·149	·0862	No.
Bg. St. I.	619	120	·630	·0512	·03225	18·72	2·071	·0754	Skin
Bo. R.	416	120	·630	·0492	·03100	17·73	2·115	·0862	Skin

➤ Signifies that the tool was capable of further cutting.

Brands of Tool Steel:—Bg. St. I. = Bergische Stahl Industrie.
Bo. T. B. = Böhler Titan Boreas.
Bo. R. = Böhler Rapid.
P. D. = Poldi Diamant 000.
P. S. = Poldi Schnelldreher.

Table D.—Analysis of Materials operated upon.

Substance.	Cast Iron. %	Cast Steel 26 to 32 tons per sq. in. %	Siemens-Martin Steel. 26 tons per sq. in. %	40 tons per sq. in. %	49 tons per sq. in. %	Sq. Shaft 40 tons per sq. in. %
Carbon	3·91 total of which 3·46 is graphite.	0·58	0·30	0·54	0·63	0·50
			A	B	C	
Silicon	2·05	0·18	0·05	0·21	0·20	0·22
Manganese	1·00	1·27	0·58	0·93	1·22	0·52
Sulphur	0·10	0·03	0·05	0·025	0·05	0·015
Phosphorus	0·23	0·02	0·07	0·05	0·05	0·04
Copper	0·07	0·12	0·11	0·10	0·14	0·13
Aluminium	0·01	0·06	0·01	0·01	0·01	0·07
Nickel and Cobalt..	0·08	0·04	0·02	0·04	0·08	0·07
Magnesium	..	Trace	Trace	..	..	..
Iron	92·55	97·70	98·81	98·095	97·62	98·435
	100	100	100	100	100	100

These results have been plotted in Plate XII., so as to show the relation between cutting speeds and areas of cut, as already described for plates III. and IV. The thick full lines show the

German results for Siemens-Martin steel, the thin lines those obtained in the trials of this report for Whitworth fluid-pressed steel. For cast iron the German results are plotted as a thick broken line, whilst the region between the curves for the soft and medium cast iron trials of this report is shown hatched.

The thick dot and dash curve shows the German results for cast steel.

TABLES.

TABLE I.—

1 TOOL STEEL MAKER (Arranged alphabetically)	2 Name of Brand of Steel.	3 No. of Trial	4 Intended Speed	5 & 6 Intended Cut and Traverse	7 Actual Speed
Object of Trial :—To obtain Maximum Cutting Speed					
			Ft. per min	Inches	Feet
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	1	200		193·0
Samuel Buckley	Bohler ✱ Rapid self-hard	9	100		106·0
John Brown & Co.	Atlas self-hard Steel	7	150	$\frac{1}{16}$	163·5
C. Cammell & Co.	Special self-hardening Steel	13	150	by	149·2
T. Firth & Sons	N.F.K. Speedicut	5	130		128·0
Samuel Osborn & Co.	Mushet high-speed Steel	3	110	$\frac{1}{16}$	114·0
Seebohm & Dieckstahl	New capital high-speed Steel	15	130		124·5
Vickers Sons & Maxim	High-speed Steel	11	130		132·5
Means....					138·8
Object of Trial : —To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	2	110		111·0
Samuel Buckley	Bohler ✱ Rapid self-hard	10	100		108·0
John Brown & Co.	Atlas self-hard Steel	8	100	$\frac{3}{16}$	98·6
C. Cammell & Co.	Special self-hardening Steel	14	120	by	121·0
T. Firth & Sons	N.F.K. Speedicut	6	80		93·5
Samuel Osborn & Co.	Mushet high-speed Steel	4	75·85	$\frac{1}{16}$	83·0
Seebohm & Dieckstahl	New capital high-speed Steel	16	100		100·9
Vickers Sons & Maxim . ..	High-speed Steel	12	110		106·4
Means....					102 8
Object of Trial :—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	38	75		74·0
Samuel Buckley	Bohler ✱ Rapid self-hard	31	40		38.73
John Brown & Co.....	Atlas self-hard Steel	40	60	$\frac{3}{16}$	63·5
C. Cammell & Co.	Special self-hardening Steel	29	60	by	61·06
T. Firth & Sons	N.F.K. Speedicut	35	65·70	$\frac{1}{8}$	66·6
Samuel Osborn & Co.	Mushet high-speed Steel	27	75		72·88
Seebohm & Dieckstahl .. .	New capital high-speed Steel	33	60		52·2
Means....					61·28
Object of Trial :—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	39	60		54·5
Samuel Buckley	Bohler ✱ Rapid self-hard	32	25		28·96
John Brown & Co.....	Atlas self-hard Steel	41	50	$\frac{3}{8}$	50·75
C. Cammell & Co.	Special self-hardening Steel	30	35	by	37·35
T. Firth & Sons	N.F.K. Speedicut	36	50·60		52·5
Samuel Osborn & Co.	Mushet high-speed Steel	28	45	$\frac{1}{8}$	49·3
Seebohm & Dieckstahl	New capital high-speed Steel	34	40		38·30
Means....					44.53

SOFT STEEL.

8	9	10	11	12	13	14	15	16	17
Actual		Area of Section of Cut	Duration of Trial	Area Machined		Weight Removed		Cause of Withdrawal	Relative condition of tool after trial
Cut	Traverse			Total	Per min.	Total	Per min.		
for 20 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.									
Inches	Inches	Sq. ins.	Minutes	Sq. feet	Sq. feet	Lbs.	Lbs.		
0·054	0 0626	0·00338	7·5	7·56	1·00	15·75	2·1	Tool failed	7
0·0585	0·0625	0·00365	20	11·05	0·552	27·75	1·387	Time up	1
0·0605	0·063	0·00381	6	5·14	0·856	11·75	1·96	Tool failed	7
0·052	0 0624	0·00325	20	15·5	0·755	34·5	1·72	Time up	2
0·0585	0·0627	0·00367	20	13·4	0·67	27·75	1·387	do.	5
0·055	0·0625	0·00344	20	11·9	0·595	26·5	1·325	do.	2
0·0595	0·0625	0·00372	17·83	11·55	0 648	28·0	1·57	Tool failed	6
0·058	0·0625	0·00362	20	14·25	0·712	29·0	1·45	Time up	2
		0·00357							
for 20 minutes with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.									
0·170	0·0624	0·0106	20	11·5	0·575	82·75	4·137	Time up	1
0·170	0·0619	0·01058	7·25	4·14	0·56	29·0	3·92	Tool failed	4
0·1805	0·0625	0 01280	5·53	2·8	0·520	19·0	3·56	do.	6
0·177	0·0620	0·01096	6·16	3·84	0·623	27·25	4·43	do.	5
0·164	0·0621	0·01018	20·0	9·95	0·497	64·5	3·225	Time up	1
0·1670	0·0622	0·01038	20·0	8·56	0·428	58·0	2·9	do.	1
0·1855	0·0571	0·01060	1·585	0·769	0·4859	6·25	3·94	Tool failed	8
0·172	0·0607	0·01040	6·66	3·58	0·537	25·5	3·89	do.	6
		0·01081							
for 20 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.									
0·172	0·125	0·0215	20	15·88	0·769	104·75	5·28	Time up	4
0·1810	0·125	0·0226	20	8 036	0·4018	60·5	3·025	do.	1
0·1590	0·125	0·0199	20	13·22	0·661	88·25	4·41	do.	2
0·159	0·125	0·0199	20	12·7	0·635	88·25	4·162	do.	2
0·1725	0·125	0·02155	20	13·75	0·687	93·0	4·65	do.	4
0·1627	0·125	0·02035	20	15·18	0·759	95·5	4·77	do.	4
0·1485	0·124	0·0185	10·58	5·66	0·535	35·25	3·34	Tool failed	7
		0·02061							
for 20 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.									
0·321	0·125	0·0401	20	11·7	0·585	147·0	7·35	Time up	2
0·3705	0·125	0·0463	20	6·01	0·300	90·75	4·53	do.	1
0·3475	0·122	0·0424	20	10·22	0·511	150·0	7·5	do.	2
0·370	0·124	0·04625	20	7·71	0·385	112·0	5·6	do.	2
0·294	0·124	0·0368	20	11·16	0·558	134·0	6·7	do.	2
0·3235	0·125	0·0404	20	10·25	0·5125	133·0	6·65	do.	2
0·3385	0·124	0·0423	20	7·91	0·395	110·5	5·52	do.	7
		0·04222							

TABLE II.—

1 TOOL STEEL MAKER (Arranged alphabetically)	2 Name of Brand of Steel	3 No. of Trial	4 5 & 6 INTENDED Speed	Cut and Traverse	7 ACTUAL Speed
Object of Trial:—To obtain Maximum Cutting Speed					
			Ft. per min	Inches	Ft. per min
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	79	110		109·0
Samuel Buckley	Bohler ✱ Rapid self-hard	91	100		105·0
John Brown & Co.	Atlas self-hard Steel	83	90	$\frac{1}{16}$	102·0
C. Cammell & Co.	Special self-hardening Steel	89	100	by	104·5
T. Firth & Sons	N.F.K. Speedicut	81	100		105·2
Samuel Osborn & Co.	Mushet high-speed Steel	87	80	$\frac{1}{16}$	93·0
Seebohm & Dieckstahl	New capital high speed steel	85	80		93·5
Average....					101·7
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co	A.W. high-speed Tool Steel	80	70		67·5
Samuel Buckley	Bohler ✱ Rapid self-hard	92	82	$\frac{3}{16}$	89·5
John Brown & Co.	Atlas self-hard Steel	84	70		74·7
C. Cammell & Co.	Special self-hardening Steel	90	80	by	80·0
T. Firth & Sons	N.F.K. Speedicut	82	85		81·6
Samuel Osborn & Co.	Mushet high-speed Steel	88	68	$\frac{1}{16}$	70·5
Seebohm & Dieckstahl	New capital high-speed Steel	86	65		66·5
Average....					75·8
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	95	50		48·5
Samuel Buckley	Bohler ✱ Rapid self-hard	94	55		54·1
John Brown & Co.	Atlas self-hard Steel	99	50	$\frac{3}{16}$	49·4
C. Cammell & Co.	Special self-hardening Steel	102	70	by	61·2
T. Firth & Sons	N.F.K. Speedicut	97	50		51·5
Samuel Osborn & Co.	Mushet high-speed Steel	103	48	$\frac{1}{8}$	49·9
Seebohm & Dieckstahl	New capital high-speed Steel	105	50		51·4
Average....					52·3
Object of Trial:—To obtain Maximun Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	96	40		39·0
Samuel Buckley	Bohler ✱ Rapid self-hard	93	35·40	$\frac{3}{8}$	36·0
John Brown & Co.	Atlas self-hard Steel	100	40		37·9
C. Cammell & Co.	Special self-hardening Steel	101	50	by	38·5
T. Firth & Sons	N.F.K. Speedicut	98	38	$\frac{1}{8}$	36·6
Samuel Osborne & Co.	Mushet high-speed Steel	104	38		37·5
Seebohm & Dieckstahl	New capital high-speed Steel	106	40		38·6
Average....					37·7

MEDIUM STEEL.

8	9	10	11	12	31	14	15	16	17
Actual		Area of Section of Cut	Duration of Trial	Area Machined		Weight removed		Cause of Withdrawal	Relative condition of tool after trial
Cut	Traverse			Total	Per Min.	Total	Per min.		
for 30 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.									
Inches	Inches	Sq. ins.	Minutes	Sq. feet	Sq. feet	Lbs.	Lbs.		
0·036	0·0625	0·00225	30	17·05	0·572	30·25	1·008	Time up	2
0·0615	0·0625	0·00384	30	16·45	0·548	42·5	1·42	do.	1
0·0635	0·0625	0·00397	30	15·9	0·535	41·25	1·37	do.	6
0·060	0·0625	0·00375	30	16·3	0·543	39·25	1·308	do.	2
0·0625	0·0625	0·0039	30	16·43	0·547	45·0	1·50	do.	2
0·0615	0·0625	0·00384	30	14·28	0·476	36·0	1·20	do.	2
0·0605	0·0625	0·00378	30	14·60	0·486	37·5	1·25	do.	6
		0·00362							
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.									
0·191	0·0625	0·0119	30	10·55	0·3516	77·25	2·57	Time up	1
0·195	0·0625	0·0122	10	4·18	0·418	34·0	3·4	Tool failed	6
0·185	0·0625	0·01148	30	12·0	0·4	89·25	2·97	Time up	5
0·182	0·0625	0·0114	30	12·5	0·417	95·0	3·17	do.	2
0·186	0·0625	0·01162	26·75	10·85	0·406	85·0	3·18	Tool failed	6
0·1785	0·0625	0·01120	30	10·95	0·365	80·25	2·675	Time up	2
0·184	0·0625	0·0115	30	10·45	0·348	78·25	2·608	do.	4
		0·01161							
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.									
0·171	0·125	0·0214	30	15·1	0·503	104·0	3·47	Time up	1
0·180	0·125	0·0225	21·25	11·9	0·56	89·75	4·22	Tool failed	6
0·172	0·125	0·0215	13·78	7·1	0·515	50·25	3·66	do.	4
0·187	0·125	0·0229	9	5.72	0·636	42·25	4·7	do.	5
0·1815	0·125	0·0227	28·33	12·4	0·498	91·0	3·85	do.	6
0·174	0·125	0·02175	30	15·6	0·52	110·5	3·68	Time up	3
0·184	0·125	0·02275	30	16·16	0·539	116·25	3·88	do.	2
		0·02222							
for 30 minutes with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.									
0·335	0·125	0·0418	30	12·2	0·407	165·75	5·53	Time up	3
0·349	0·125	0·04365	30	11·6	0·390	160·0	5·3	do.	1
0·346	0·125	0·04325	21·666	8·51	0·393	120·75	5·58	Tool failed	5
0 329	0·125	0·0412	18·25	7·18	0·393	95·25	5·22	do.	6
0·327	0·125	0·0408	27	10·25	0·38	142·25	5·28	do.	7
0·345	0·125	0·0432	30	11·75	0·392	164·0	5·47	Time up	4
0·340	0·125	0·0425	30	12·10	0·403	166·75	5·558	do.	2
		0·04234							

TABLE III.—

1 TOOL STEEL MAKER. (Arranged alphabetically)	2 Name of Brand of Steel.	3 No. of Trial.	4 5 & 6 INTENDED. Speed	Cut and Traverse	7 ACTUAL Speed
Object of Trial:—To obtain Maximum Cutting Speed					
			Ft. per min.	Inches.	Ft. per min.
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	139	50		52·5
Samuel Buckley	Bohler ✳ Rapid self-hard	143	55		59·5
John Brown & Co.	Atlas self-hard Steel	133	47	$\frac{1}{16}$	49·75
C. Cammell & Co.	Special self-hardening Steel	137	60	by	58·0
T. Firth & Sons	N.F.K Speedicut	131	45		46·8
Samuel Osborn & Co.	Mushet high-speed Steel	141	50	$\frac{1}{16}$	56·2
Seebohm & Dieckstahl	New capital high-speed Steel	135	60		59·1
Average....					54
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	140	40		40
Samuel Buckley	Bohler ✳ Rapid self-hard	144	40		41·2
John Brown & Co.	Atlas self-hard Steel	134	45	$\frac{3}{16}$	42·5
C. Cammell & Co.	Special self-hardening Steel	138	40	by	40·5
T. Firth & Sons	N.F.K. Speedicut	132	40		40·6
Samuel Osborn & Co.	Mushet high-speed Steel	142	40	$\frac{1}{16}$	38·8
Seebohm & Dieckstahl	New capital high-speed Steel	136	45		43·5
Average....					41·01
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	153	28		30·8
Samuel Buckley	Bohler ✳ Rapid self-hard	155	30		30·7
John Brown & Co.	Atlas self-hard Steel	145	35	$\frac{3}{16}$	31·9
C. Cammell & Co.	Special self-hardening Steel	149	30	by	32·6
T. Firth & Sons	N.F.K. Speedicut	157	28		30
Samuel Osborn & Co.	Mushet high-speed Steel	151	30	$\frac{1}{8}$	29·9
Seebohm & Dieckstahl	New capital high-speed Steel	147	25		26·8
Average....					30·4
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	154	20		20·8
Samuel Buckley	Bohler ✳ Rapid self-hard	156	20		18·7
John Brown & Co.	Atlas self-hard Steel	146	22	$\frac{3}{8}$	20
C. Cammell & Co.	Special self-hardening Steel	150	20	by	20
T. Firth & Sons	N F.K. Speedicut	158	20		20
Samuel Osborn & Co.	Mushet high-speed Steel	152	20	$\frac{1}{8}$	20·25
Seebohm & Dieckstahl	New capital high-speed Steel	148	17		17·6
Average....					19·61

HARD STEEL.

8	9	10	11	12	13	14	15	16	17
Actual		Area of Section of Cut	Duration of Trial	Area machined		Weight removed		Cause of Withdrawal	Relative condition of tool after trial
Cut	Traverse			Total	Per min.	Total	Per min.		
for 30 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.									
Inches	Inches	Sq. ins.	Minutes	Sq. feet	Sq. feet	Lbs.	Lbs.		
0·0635	0·0625	0·00397	30	8·2	0·273	21·75	0·725	Time up	1
0·066	0·0625	0·00412	29·33	9·089	0·310	25·5	0·870	Tool failed	5
0·0625	0·0625	0·00390	30	7·7	0·29	20·25	0·675	Time up	1
0·058	0·0625	0·00362	19·066	5·75	0·302	14·75	0·780	Tool failed	5
0·0525	0·0625	0·00328	30	7·20	0·240	16·25	0·542	Time up	1
0·0610	0·0625	0·00381	30	8·76	0·292	21	0·700	do.	4
0·056	0·0625	0·00350	21·75	6·69	0·308	15·5	0·713	Tool failed	5
		0·00374							
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.									
0·1905	0·0625	0·0119	30	6.25	0·208	48·0	1·600	Time up	3
0·1985	0·0625	0·0124	30	6·44	0·214	51·25	1·708	do.	1
0·192	0·0625	0·0120	6·916	1·55	0·222	12·0	1·730	Tool failed	4
0·188	0·0625	0·01173	19·6	4·14	0·211	32·75	1·630	do.	4
0·1875	0·0625	0·0117	30	6·35	0·212	48·75	1·625	Time up	1
0·1873	0·0625	0·0117	23·066	4·66	0·202	36·0	1·560	Tool failed	4
0·1855	0·0625	0·0116	12·25	2·75	0·226	20·25	1·650	do.	4
		0·01186							
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.									
0·175	0·125	0·0219	30	9·6	0·32	69·0	2·300	Time up	2
0·1875	0·125	0·0234	16·916	5·042	0·32	41·25	2·450	Tool failed	2
0·1872	0·125	0·0234	6·8	2·260	0·333	15·5	2·280	do.	2
0·1830	0·125	0·0229	24·47	8·330	0·34	60·5	2·475	do.	1
0·181	0·125	0·02265	10	3·130	0·313	21·75	2·175	do.	2
0·184	0·125	0·0230	18·85	5·850	0·311	44·75	2·380	do.	2
0·196	0·125	0·0245	11·166	3·100	0·280	23·0	2·070	do.	2
		0·0231							
for 30 minutes with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.									
0·362	0·125	0·0452	30	6·500	0·2166	92·75	3·092	Time up	2
0·371	0·125	0.0464	30	5·850	0·1950	90·75	3·025	do.	2
0·328	0·125	0·0410	30	6·230	0·2077	82·75	2·758	do.	5
0·353	0·125	0·0441	30	6·230	0·2077	90·0	3·000	do.	1
0·343	0·125	0·0429	30	6·230	0·2077	86·75	2·892	do.	5
0·362	0·125	0·0452	30	6·300	0·2100	93·0	3·100	do.	4
0·332	0·125	0·0415	30	5·500	0·1833	75·0	2·500	do.	7
		0·0438							

TABLE IV.—

1 TOOL STEEL MAKER (Arranged alphabetically)	2 Name of Brand of Steel,	3 No. of Trial	4 5 & 6 INTENDED Speed	Cut and Traverse	7 ACTUAL Speed
Object of Trial:—To obtain Maximum Cutting Speed					
			Ft. per min	Inches	Ft. per min
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	167	102		101·5
Samuel Buckley	Bohler ✱ Rapid self-hard	165	110		112·0
John Brown & Co.	Atlas self-hard Steel	171	100	$\frac{1}{16}$	107·0
C. Cammell & Co.	Special self-hardening Steel	161	108	by	109·0
T. Firth & Sons	N.F.K. Speedicut	170	106		107·0
Samuel Osborn & Co.	Mushet high-speed Steel	163	106	$\frac{1}{16}$	103·5
Seebohm & Dieckstahl	New capital high-speed Steel	159	104·7		103·5
Average....					106·2
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	168	85		89·0
Samuel Buckley	Bohler ✱ Rapid self-hard	166	80		80·2
John Brown & Co.	Atlas self-hard Steel	172	90	$\frac{3}{16}$	89·0
C. Cammell & Co.	Special self-hardening Steel	162	80	by	82·1
T. Firth & Sons	N.F.K. Speedicut	169	100		99·5
Samuel Osborn & Co.	Mushet high-speed Steel	164	86	$\frac{1}{16}$	84·7
Seebohm & Dieckstahl	New capital high-speed Steel	160	71·3		71·0
Average....					85·1
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	182	67		66·2
Samuel Buckley	Bohler ✱ Rapid self-hard	177	61		62
John Brown & Co.	Atlas self-hard Steel	185	62	$\frac{3}{16}$	61·5
C. Cammell & Co.	Special self-hardening Steel	173	70	by	72
T. Firth & Sons	N.F.K. Speedicut	179	60		64
Samuel Osborn & Co.	Mushet high-speed Steel	175	55	$\frac{1}{8}$	58·2
Seebohm & Dieckstahl	New capital high-speed Steel	186	60		60·9
Average....					63·5
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	183	55		55·5
Samuel Buckley	Bohler ✱ Rapid self-hard	178	51		49
John Brown & Co.	Atlas self-hard Steel	184	53	$\frac{3}{8}$	53
C. Cammell & Co.	Special self-hardening Steel	174	43	by	43·8
T. Firth & Sons	N.F.K. Speedicut	180	50		53·2
Samuel Osborn & Co.	Mushet high-speed Steel	176	45	$\frac{1}{8}$	48·5
Seebohm & Dieckstahl	New capital high-speed Steel	187	52·25		52·25
Average....					50·75

SOFT CAST IRON.

8	9	10	11	12	13	14	15	16	17
Actual		Area of Section of Cut	Duration of Trial	Area Machined		Weight removed		Cause of Withdrawal	Relative condition of tool after trial
Cut	Traverse			Total	Per min.	Total	Per min.		
for 30 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.									
Inches	Inches	Sq. ins.	Minutes	Sq. feet	Sq. feet	Lbs.	Lbs.		
0·0655	0·0625	0·00409	30	15·8	0·527	37·25	1·242	Time up	1
0·060	0·0625	0·00375	20·5	11·9	0·582	25·5	1·24	Tool failed	5
0·0635	0·0625	0·00397	30	16·75	0·558	37·75	1·258	Time up	4
0·0625	0·0625	0·0039	30	17·02	0·567	39·0	1·300	do.	1
0·064	0·0625	0·004	14·916	8·38	0·558	19·0	1·275	Tool failed	5
0·019	0·0625	0·00118	16	8·58	0·539	11·75	0·735	do.	7
0·063	0·0625	0·00394	30	16·18	0·539	38·0	1·267	Time up	1
		0·00355							
for 30 minutes with $\frac{2}{16}$in. cut by $\frac{1}{16}$in. traverse.									
0·1975	0·0625	0·0124	30	13·9	0·463	95·0	3·167	Time up	4
0·197	0·0625	0·0123	9	3·75	0·417	26·0	2·889	Tool failed	6
0·186	0·0625	0·0116	1·333	0·615	0·463	3·0	2·29	do.	7
0·196	0·0625	0·01225	30	12·8	0·427	91·75	3·058	Time up	1
0·1975	0·0625	0·0124	30	15·55	0·518	108·5	3·602	do.	4
0·194	0·0625	0·0121	30	13·22	0·441	92·25	3·175	do.	1
0·198	0·0625	0·0124	30	11·1	0·370	76·25	2·542	do.	1
		0·01221							
for 30 minutes with $\frac{2}{16}$in. cut by $\frac{1}{8}$in. traverse.									
0·171	0·125	0·0214	30	20·7	0·69	131·5	4·383	Time up	4
0·170	0·125	0·0213	26·816	17·3	0·646	116·25	4·330	Tool failed	3
0·151	0·125	0·0189	25·016	16·01	0·64	98·5	3·94	do.	4
0·126	0·125	0·01575	30	22·5	0·75	93·0	3·100	Time up	4
0·1825	0·125	0·0228	30	20·01	0·667	126·25	4·208	do.	2
0·185	0·125	0 0237	30	18·2	0·607	125·25	4·175	do.	1
0·171	0·125	0·0214	21	13·86	0·686	86·75	4·125	Tool failed	4
		0·02075							
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.									
0·366	0·125	0·0459	30	17·35	0·578	223·75	7·458	Time up	6
0·379	0·125	0·0474	30	15·36	0·512	215·5	7·183	do.	1
0·336	0·125	0·042	30	16·6	0·552	209·0	6·967	do.	6
0·368	0·125	0·046	30	13·7	0·457	186·0	6·200	do.	1
0·37	0·125	0·0462	30	16·62	0·554	220·0	7·330	do.	1
0·369	0·125	0·046	30	15·2	0·507	201·0	6·700	do.	1
0·364	0·125	0·0455	30	16·4	0·547	219·75	7·325	do.	5
		0·0456							

TABLE V.—

1 TOOL STEEL MAKER (Arranged alphabetically)	2 Name of Brand of Steel	3 No. of Trial	4 Intended Speed	5 & 6 Intended Cut and Traverse	7 Actual Speed
Object of Trial:—To obtain Maximum Cutting Speed					
			Ft. per min	Inches	Ft. per min
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	52	50		50·7
Samuel Buckley	Bohler ✱ Rapid self-hard	42	50		51·8
John Brown & Co.	Atlas self-hard Steel	50	65	$\frac{1}{16}$	62·0
C. Cammell & Co.	Special self-hardening Steel	54	70	by	68·5
T. Firth & Sons	N.F.K. Speedicut	46	55		56·88
Samuel Osborn & Co.	Mushet high-speed Steel	44	70	$\frac{1}{16}$	69·0
Seebohm & Dieckstahl	New capital high-speed Steel	48	60		59·7
Average....					59·8
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	53	40		40·3
Samuel Buckley	Bohler ✱ Rapid self-hard	43	50	$\frac{3}{16}$	49·0
John Brown & Co.	Atlas self-hard Steel	51	50	by	48·8
C. Cammell & Co.	Special self-hardening Steel	55	50		50·2
T. Firth & Sons	N.F.K. Speedicut	47	45	$\frac{1}{16}$	44·24
Samuel Osborn & Co.	Mushet high-speed Steel	45	50		49·8
Seebohm & Dieckstahl	New capital high-speed Steel	49	50		51·2
Average....					47·65
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	58			33·1
Samuel Buckley	Bohler ✱ Rapid self-hard	64	50		50
John Brown & Co.	Atlas self-hard Steel	60	33	$\frac{3}{16}$	30·3
C. Cammell & Co.	Special self-hardening Steel	56	30	by	31·9
T. Firth & Sons	N.F.K. Speedicut	62	30		34·4
Samuel Osborn & Co.	Mushet high-speed Steel	68	35	$\frac{1}{8}$	34·4
Seebohm & Dieckstahl	New capital high-speed Steel	66	40		36·6
Average....					35·8
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	59	28		27·7
Samuel Buckley	Bohler ✱ Rapid self-hard	65	25		24·35
John Brown & Co.	Atlas self-hard Steel	61	25	$\frac{3}{8}$	25·2
C. Cammell & Co.	Special self-hardening Steel	57	25	by	25·6
T. Firth & Sons	N.F.K. Speedicut	63	20		22·0
Samuel Osborn & Co.	Mushet high-speed Steel	69	25	$\frac{1}{8}$	25·1
Seebohm & Dieckstahl	New capital high-speed Steel	67	28		25·4
Average....					25·0

MEDIUM CAST IRON.

8	9	10	11	12	13	14	15	16	17
Actual		Area of Section	Duration of	Area Machined		Weight removed			
Cut	Traverse	Cut	Trial	Total	Per min.	Total	Per min.	Cause of Withdrawal	Relative conditions of tool after trial
for 30 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.									
Inches	Inches	Sq. ins.	Minutes	Sq. feet	Sq. feet	Lbs.	Lbs.		
0·0610	0·0610	0·00381	30	7·95	0·265	18·25	0·608	Time up	2
0·059	0·0625	0·00368	30	8·091	0·269	19·25	0·642	do.	1
0·0465	0·0624	0·0029	13	4·3	0·33	7·0	0·54	Tool failed	4
0·056	0·0625	0·00350	10·3	3·68	0·358	8·5	0·825	do.	3
0·063	0·0625	0·00393	19·75	5·78	0·292	13	0·658	do.	4
0·050	0·0624	0·00313	1·83	0·702	0·382	1	0·545	do.	4
0·053	0·0624	0·00331	30·0	9·26	0·308	20·75	0·69	Time up	4
		0·00347							
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.									
0·159	0·062	0·00986	30	6·22	0·207	38·5	1·28	Time up	2
0·1840	0·0623	0·0115	30	7·618	0·254	52	1·73	do.	1
0·176	0·0625	0·0110	1	0·24	0·24	1·75	1·75	Tool failed	2
0·174	0·062	0·0109	5·66	1·42	0·25	9·5	1·68	do.	2
0·1685	0·0625	0·0105	8·41	1·94	0·230	12	1·42	do.	2
0·1560	0·0624	0·0097	8·1	2·08	0·256	12·75	1·575	do.	2
0·173	0·062	0·0108	17·21	4·54	0·26	30·75	1·77	do.	2
		0·0106							
for 30 minules with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.									
0·1815	0·125	0·0227	30	10·1	0·335	67	2·23	Time up	1
0·1770	0·125	0·0221	1·41	0·726	0·51	4·25	3·0	Tool failed	7
0·1625	0·125	0·0203	10	3·27	0·327	18·5	1·85	do.	4
0·140	0·123	0·0175	30	9·8	0·327	57·25	1·908	Time up	2
0·175	0·125	0·0219	26·8	9·05	0·337	58	2·16	Tool failed	4
0·178	0·125	0·0223	17·33	6·12	0·352	40·75	2·34	do.	4
0·175	0·125	0·0219	12	4·57	0·38	28	2·33	do.	2
		0·02124							
for 30 minutes with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.									
0·298	0·125	0·0373	15	4·35	0·29	46·5	3·1	Tool failed	7
0·356	0·124	0·0446	30	7·47	0·249	99·5	3·32	Time up	1
0·281	0·124	0·0351	10	2·58	0·258	26	2·6	Tool failed	3
0·321	0·123	0·0401	7·25	1·92	0·264	21·75	3·0	do.	3
0·352	0·124	0·0440	30	6·83	0·227	88·5	2·95	Time up	1
0·326	0·125	0·0407	5·75	1·5	0·261	17	2·96	Tool failed	3
0·302	0·124	0·0377	9·0	2·51	0·279	23·75	2·64	do.	3
		0·0399							

TABLE VI.—

1 TOOL STEEL MAKER (Arranged alphabetically)	2 Name of Brand of Steel	3 No. of Trial	4 5 & 6 INTENDED Speed	 Cut and Traverse	7 ACTUAL Speed
	Object of Trial:—To obtain Maximum Cutting Speed				
			Ft. per min	Inches	Ft. per min
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	107	32·0		36·4
Samuel Buckley	Bohler * Rapid self-hard	190	35·0		31·1
John Brown & Co.	Atlas self-hard Steel	113	35-40	$\frac{1}{16}$	38·5
C. Cammell & Co.	Special self-hardening Steel	109	35·0	by	38·6
T. Firth & Sons	N.F.K. Speedicut	117	30·0		36·0
Samuel Osborn & Co.....	Mushet high-speed Steel	121	37·0	$\frac{1}{16}$	37·5
Seebohm & Dieckstahl	New capital high-speed Steel	111	40·0		38·4
Average ..					36·65
	Object of Trial:—To obtain Maximum Cutting Speed				
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	108	30·0		30·3
Samuel Buckley	Bohler * Rapid self-hard	191	28·0		26·7
John Brown & Co.	Atlas self-hard Steel	114	33·0	$\frac{3}{16}$	30·5
C. Cammell & Co.	Special self-hardening Steel	110	30·0	by	31·9
T. Firth & Sons	N.F.K. Speedicut	120	30·0		31·8
Samuel Osborn & Co.....	Mushet high-speed Steel	122	30·0	$\frac{1}{16}$	29·5
Seebohm & Dieckstahl	New capital high-speed Steel	112	30·0		30·1
Average....					30·1
	Object of Trial:—To obtain Maximum Cutting Speed				
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	125	20·0		21
Samuel Buckley	Bohler * Rapid self-hard	189	22·0		20·8
John Brown & Co.	Atlas self-hard Steel	115	22·0	$\frac{3}{16}$	20·2
C. Cammell & Co.	Special self-hardening steel	129	25·0	by	25·0
T. Firth & Sons	N.F.K. Speedicut	118	20-25		24·7
Samuel Osborn & Co.....	Mushet high-speed Steel	124	20·0	$\frac{1}{8}$	20·1
Seebohm & Dieckstahl	New capital high-speed Steel	127	25·0		24·75
Average. ..					22·36
	Object of Trial:—To obtain Maximum Cutting Speed				
Armstrong, Whitworth & Co.	A.W. high-speed Tool Steel	126	18·0		18
Samuel Buckley	Bohler * Rapid self-hard	188	18·0		18·45
John Brown & Co.	Atlas self-hard Steel	116	18-20	$\frac{3}{8}$	17·2
C. Cammell & Co.	Special self-hardening Steel	130	20·0	by	18·1
T. Firth & Sons	N.F.K. Speedicut	119	20·0		22·0
Samuel Osborn & Co.....	Mushet high-speed Steel	123	22·0	$\frac{1}{8}$	
Seebohm & Dieckstahl	New Capital high-speed steel	128	20·0		19·5
Average....					18·88

HARD CAST IRON.

8	9	10	11	12	13	14	15	16	17
Actual		Area of Section of Cut	Duration of Trial	Area Machined		Weight removed		Cause of Withdrawal	Relative condition of tool after trial
Cut	Traverse			Total	Per min.	Total	Per min.		
for 30 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.									
Inches	Inches	Sq. ins.	Minutes	Sq. feet	Sq. feet	Lbs.	Lbs.		
0·057	0·0625	0·00356	30	5·700	0·1900	12·875	0·4292	Time up	1
0·063	0·0625	0·00398	13·25	2·15	0·1610	4·75	0·3580	Tool failed	6
0·0600	0·0625	0·00375	30	6·0	0·2000	14·5	0·4833	Time up	4
0·0575	0·0625	0·00359	30	6·03	0·2010	14	0·4666	do.	1
0·0625	0·0625	0·00390	30	5·62	0·1870	13·25	0·4417	do.	4
0·058	0·0625	0·00362	30	5·85	0·195	12·875	0·4292	do.	6
0·0605	0·0625	0·00378	30	5·98	0·1993	14	0·4667	do.	1
		0·00373							
for 30 minutes with $\frac{2}{16}$in. cut by $\frac{1}{16}$in. traverse.									
0·188	0·0625	0·01173	30	4·73	0·1577	33·5	1·117	Time up	1
0·168	0·0625	0·01048	30	4·175	0·1392	28	0·933	do.	2
0·162	0·0625	0·01010	30	4·76	0·1587	28·75	0·958	do.	6
0 1875	0·0625	0·01173	30	5·0	0·1667	35·5	1·183	do.	2
0·1850	0·0625	0·01155	13	2·15	0·1660	14·75	1·136	Tool failed	6
0·1700	0·0625	0·01061	30	4·6	0·1533	30	1·000	Time up	2
0 1790	0·0625	0·01119	30	4·7	0·1567	31·25	1·042	do.	2
		0·01105							
for 60 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.									
0·1875	0·125	0·02345	60	13·15	0·219	88·0	1·467	Time up	1
0·1380	0·125	0·01725	60	13·06	0·2177	63·25	1·054	do.	5
0·1725	0·125	0·02155	60	12·6	0·2100	81·5	1·358	do.	2
0·162	0·125	0·02025	60	15·6	0·2600	85·25	1·421	do.	3
0·169	0·125	0·02112	60	15·42	0·257	97·25	1·621	do.	7
0·174	0·125	0·02175	17	3·73	0·219	23·125	1·360	Tool failed	5
0·153	0·125	0·01912	60	15·5	0·2580	85·75	1·429	Time up	3
		0·02064							
for 30 minutes with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.									
0·365	0·125	0·0457	30	5·65	0·188	76·0	2·533	Time up	2
0·290	0·125	0·0363	30	5·78	0·193	61·25	2·417	do.	4
0·358	0·125	0·0448	30	5·38	0·179	71·75	2·392	do.	2
0·341	0·125	0·0426	30	5·65	0·1883	76·25	2·542	do.	1
0·367	0·125	0·0459	30	6·9	0·230	96·0	3·2	do.	4
	0·125							Tool failed	7
0·353	0·125	0·0441	30	6·1	0·203	79·5	2·650	Time up	4
		0·0432							

TABLE VIa.—TESTS MADE WITH

Description of Tool Steel used	Material Operated upon	No. of Trial	Actual			Area of Section of Cut.
			Speed	Cut	Traverse	
Ordinary Water Hardened	Soft Steel	17	31·2	0·0585	0·0625	0·00365
,, ,, ,,	,, ...	18	25·1	0·1765	0·0625	0·01104
,, ,, ,,	,, ...	23	40·9	0·1885	0·0625	0·01180
,, ,, ,,	,, ...	25	61·75	0·0620	0·0625	0·00378
Ordinary Mushet	,, ...	19	35·1	0·1810	0·0625	0·01130
,, ,, ...	,, ...	20	35·2	0·1805	0·0625	0·01128
,, ,, ...	,, .. .	21	40·5	0·1740	0·0625	0·01088
,, ,, ...	,, ...	24	63·0	0·0580	0·0625	0·00362
*High-speed Air Hardened	,, ...	26	25·4	0·283	0·375	0·1065
Ordinary Water Hardened	Medium Cast-iron	75	24·6	0·0625	0.0625	
,, ,, ,,	,, ,,	73	17·6	0·1875	0·0625	
,, ,, ,,	,, ,,	77	15½	0·1875	0·125	
,, ,, ,,	,, ,,	70	15	$\frac{3}{16}$	$\frac{1}{8}$	Tool
,, ,, ,,	,, ,,	71	16	$\frac{3}{16}$	$\frac{1}{8}$	,,
Ordinary Mushet	,, ,,	72	23·6	0·0625	0·0625	
,, ,, ...	,, ,,	74	19·1	0·1875	0·0625	
,, ,, ...	,, ,,	76	15	0·1875	0·125	
,, ,, ...	,, ,,	78	16	0·1875	0·125	
Ordinary Water Hardened	Soft Cast-iron ..	178A	22·5	0·1915	0·125	
,, ,, ,,	,, ..	178B	23·1	0.1910	0·125	
Ordinary Mushet	,, .	181	31·6	0·1860	0·125	

*Special experiment with heavy cut, see page 245.

ORDINARY STEEL TOOLS.

Duration of Trial	Horse Power Electrically Measured			Area Machined sq. ft.		Weight Removed lbs.		Cause of Withdrawal	Cutting Force on Tool
	Gross	Lost	Net	Total	Per Min.	Total	Per Min.		
Mins.									Lbs.
20	11·95	9·95	2·00	3·26	0·163	7¼	0·362	Time up	2,110
5	8·76	6·17	2·59	0·65	0·131	4	0·800	Tool failed	3,407
5·75	10·21	6·62	3·58	1·22	0·214	9½	1·65	,,	2,890
6·62	12·15	10·00	2·15	2·11	0·319	5¼	0·792	,,	1,030
20	12·96	9·76	3·20	3·67	0·183	27½	1·362	Time up	3,005
3·16	10·01	5·64	4·37	0·34	0·171	3½	1·105	Tool failed	4,090
13	12·30	9·80	2·50	2·75	0·211	18½	1·420	,,	2,040
17	12·25	10·15	2·10	5·55	0·326	13½	0·794	,,	1,010
			23·4						
5½	34·90	11·49		0·75	0·136	47	8·55	Time up	30,600
17·0	..	..	..	2·19	0·128	3½	0·191	Tool failed	..
8·37	..	..	..	0·765	0·091	5	0·600	,,	..
·83	..	..	..	..	..	1	1·2	,,	..
refused	to cut	at 15ft.	per min	..	..	..	..	,,	..
,,	,,	at 16ft.	,,	..	..	..	..	,,	..
20·5	8·1	..	..	2·51	0·122	5½	0·256	,,	..
12·33	..	..	..	1·22	0·099	8½	0·668	,,	..
1·5	..	..	..	..	..	1½	1·165	,,	..
8·53	.	..	..	..	..	8	0·94	,,	..
8·53	..	..	..	1·0	0·117	13½	1·55	Tool failed	..
8·8	8·65	6·0	2·65	1·06	0·120	13	1·48	,,	3,790
32·75	..	..	.	5·36	0·163	73½	2·25	,,	..

TABLE VII.—

1	2	3		4		5		6
TOOL STEEL MAKER	No. of Trial	Front Top Rake f°		Front Clearance C°		Side Top Rake S°		Side Clearance K°
Object of Trial :—To obtain Maximum Cutting Speed								
		Deg.	Min.	Deg.	Min.	Deg	Min.	
Armstrong, Whitw'th & Co	1			11	20	8	16	8
Samuel Buckley.....	9	27	0	9	14			12½
John Brown & Co.....	7	14	5	12	40	9	35	12
C. Cammell & Co.	13	14	40	9	56	2	50	6
T. Firth & Sons	5	8	40	12	25	10	30	11
Samuel Osborn & Co....	3	8	32	10	45	19	3	16
Seebohm & Dieckstahl ..	15	15	5	16	3	9	56	14
Vickers Sons & Maxim ..	11	9	22	10	37	0	43	13
Object of Trial :—To obtain Maximum Cutting Speed								
Armstrong, Whitw'th & Co	2	14	5	10	0	10	0	10
Samuel Buckley	10	20	0	7	10			11
John Brown & Co.....	8	14	5	9	14	1	4	10
C. Cammell & Co.....	14	14	50	8	3	3	35	7
T. Firth & Sons	6	11	20	7	13	4	3	9
Samuel Osborn & Co. ..	4	11	6	6	0	16	0	7
Seebohm & Dieckstahl ..	16	20	20	7	30	13	42	7
Vickers Sons & Maxim ..	12	6	50	13	42	5	4	11
Object of Trial :—To obtain Maximum Cutting Speed								
Armstrong, Whitw'th & Co	38	13	20	10	36	7	48	14
Samuel Buckley.....	31	19	50	6	46			11
John Brown & Co... ...	40	12	0	12	0	9	12	11
C. Cammell & Co.	29	9	56	15	25	11	20	11
T. Firth & Sons	35	11	30	9	12	7	10	9
Samuel Osborn & Co. ..	27	6	25	8	10	14	0	7
Seebohm & Dieckstahl ..	33	16	40	12	40	12	40	11
Object of Trial :—To obtain Maximum Cutting Speed								
Armstrong Whitw'th & Co	39	12	44	8	36	7	48	11
Samuel Buckley	32	20	0	9	15			14
John Brown & Co.....	41	12	0	12	42	9	12	9
C. Cammell & Co.	30	11	20	14	5	16	20	9
T. Firth & Sons	36	8	36	10	30	8	36	10
Samuel Osborn & Co. .	28	7	29	10	38	19	20	9
Seebohm & Dieckstahl ..	34	20	35	11	20	5	0	8

SOFT STEEL.

7	8	9	10	11	12	13	14
Height above Centre	Diameter of Work		True Cutting Angle in plane of Shaving {90−(Top rake in this plane + β)}		Angle of plane of shaving	Cutting Arc	Total Weight removed
Z	2 R	β	At Start	At Finish	θ		
for 20 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.							
Inches	Inches	Deg. Min.	Deg. Min.	Deg. Min.	Deg. Min.	Inches	Lbs.
0·725	20·78	4 0	66 40	66 40			15·75
0·500	19·811	2 54	60 6	60 6	29 22	0·15	27·75
0·8125	19·945	4 40	71 7	71 7		0·17	11·75
0·2813	19·59	1 39	69 42	68 21	23 0	0·19	34·5
——	20·175	——	80 30	78 40	7 50	0·23	27·75
0·69	20·69	3 49	73 26	73 26	21 30	0·23	26·5
0·125	19·467	0 44	71 16	71 16	29 54	0·17	28·0
0·100		0 37	78 4	77 0	16 42	0·20	29·0
for 20 minutes with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.							
1·0	20·48	5 37	61 34	60 3	16 45	0·34	82·75
0·5	19·585	2 56	64 4	64 4	45 0	0·50	29·0
0·75	19·953	4 19	59 17	59 17	33 2	0·31	19·0
0·5	19·575	2 56	72 1	67 44	28 50	0·325	27·25
1·0	20·479	5 37	73 3	65 25	24 23	0·410	64·5
0·625	20·134	3 34	59 56	59 56	26 30	0·420	58·0
0·125	19·151	0 45	55 45	55 45	50 12	0·240	6·25
0·100	19·575	0 35	77 5	75 20	28 50	0·37	25·5
for 20 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.							
1·0625	16·378	7 30	68 28	60 30	29 55	0·42	104·75
0·5	17·744	3 17	62 12	60 0	36 0	0·35	60·5
0·75	16·058	5 22	69 14	60 48	28 50	0·32	88·25
1·0	18·294	6 18	70 2	62 4	29 20	0·34	83·25
0·875	17·398	5 50	71 28	65 28	28 50	0·46	93·0
0·4375	18·690	2 41	72 19	69 15	28 50	0·44	95·5
0·75	19·690	4 50	58 35	58 35	41 10	0·35	35·25
for 20 minutes with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.							
1·0	16·1	7 2	67 34	61 0	35 0	0·62	147·0
0·5	17·546	3 16	63 44	63 44	32 0	0·65	90·75
0·75	15·320	5 36	68 24	60 14	37 48	0·62	150·0
1·0	18·277	6 18	64 22	64 22	42 50	0·54	112·0
1·0	17·126	6 45	71 45	67 45	32 30	0·77	134·0
0·75	18·095	4 46	66 34	63 14	40 20	0·65	133·0
0·875	16·855	5 58	61 37	61 37	38 50	0·46	110·5

TABLE VIII.—

1	2	3	4	5	6
TOOL STEEL MAKER	No. of Trial	Front Top Rake f°	Front Clearance C°	Side Top Rake S°	Side Clearance K°
Object of Trial:—To obtain Maximum Cutting Speed					
		Deg. Min.	Deg. Min.	Deg. Min.	
Armstrong, Whitw'th & Co	79	10 37	12 0	8 36	9
Samuel Buckley.....	91	19 46	8 30		13
John Brown & Co.....	83	11 20	12 40	12 0	9
C. Cammell & Co.	89	13 22	11 20	7 50	6
T. Firth & Sons.....	81	13 22	16 40	15 0	10
Samuel Osborn & Co....	87	14 43	11 20	20 40	11
Seebohm & Dieckstahl ..	85	9 55	13 45	16 5	11
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	80	12 41	9 50	10 40	10
Samuel Buckley.....	92	18 6	10 30		11
John Brown & Co.....	84	14 43	12 40	9 15	9
C. Cammell & Co.	90	13 22	11 20	7 10	5
T. Firth & Sons.... ...	82	14 22	15 20	12 0	11
Samuel Osborn & Co....	88	12 41	12 50	20 0	11
Seebohm & Dieckstahl ..	86	7 8	14 2	20 40	8
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	95	12 41	10 0	9 15	7
Samuel Buckley.....	94	17 15	7 10		11
John Brown & Co.....	99	14 5	10 0	10 13	12
C. Cammell & Co.	102	10 37	18 40	16 40	11
T. Firth & Sons	97	10 37	16 42	16 40	11
Samuel Osborn & Co....	103	14 43	14 42	19 50	6
Seebohm & Dieckstahl ..	105	14 43	5 0	8 30	6
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	96	12 41	11 20	7 10	8
Samuel Buckley.....	93	20 20	7 30		13
John Brown & Co.....	100	12 0	11 20	9 10	11
C. Cammell & Co.	101	9 55	20 35	18 0	11
T. Firth & Sons	98	14 43	10 36	18 40	7
Samuel Osborn & Co....	104	15 23	14 2	18 0	10
Seebohm & Dieckstahl ..	106	17 22	7 10	9 15	8

MEDIUM STEEL.

7	8	9	10	11	12	13	14
Height above Centre	Diameter of Work		True Cutting Angle in plane of shaving { 90—(Top rake in this plane + β) }		Angle of plane of shaving	Cutting Arc	Total Weight removed
Z	2 R	β	At Start	At Finish	θ		
for 30 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.							
Inches	Inches	Deg. Min.	Deg. Min.	Deg. Min.	Deg. Min.	Inches	Lbs.
0·375	17·92	2 34	69 6	67 23	20 20	0·20	30·25
0·625	15·705	4 4	62 46	61 51	23 50	0·17	42·5
0·625	17·296	4 8	68 37	61 51	22 50	0·175	41·25
0·750	16·243	5 18	69 42	64 37	17 15	0·160	39·25
1·0	17·868	6 26	65 34	63 19	19 20	0·2	45·0
0·625	17·334	4 8	64 32	64 32	15 40	0·175	36·0
0·625	16·761	4 16	68 4	65 14	23 50	0·15	37·5
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.							
0·375	17·538	2 28	72 32	67 42	26 30	0·375	77·25
0·625	15·314	4 42	58 16	58 0	28 20	0·35	54·0
0·625	16·927	4 14	66 6	61 50	23 10	0·375	89·25
0·75	15·879	5 26	66 4	61 50	24 10	0·35	95·0
1·0	17·496	6 26	65 19	65 19	19 20	0·38	85·0
0·75	16·977	5 1	65 4	61 34	29 40	0·44	80·25
0·75	16·393	5 16	66 5	65 8	32 10	0·38	78·25
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.							
0·375	14·963	2 53	71 50	67 50	18 50	0·375	104·0
0·625	15·344	4 36	63 14	62 14	22 0	0·4	89·75
0·5	13·911	4 50	68 20	66 16	25 40	0·35	50·25
1·0	13·19	8 44	64 56	64 56	22 50	0·42	42·25
0·375	14·943	2 50	63 10	63 10	26 30	0·4	91·0
0·624	12·48	5 45	62 15	61 10	29 20	0·45	110·5
0·1875	12·112	1 46	72 4	66 15	31 0	0·42	116·25
for 30 minutes with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.							
0·375	14·289	3 1	70 49	60 49	31 20	0·575	165·75
0·625	15·84	4 32	58 24	58 24	26 10	0·675	160·0
0·4375	13·563	3 42	68 12	65 15	33 0	0·55	120·75
0·8125	12·906	7 15	64 45	62 30	22 20	0·63	95·25
0·5	14·29	4 3	67 47	65 40	31 0	0·75	142·25
0·8125	13·563	6 54	63 6	61 10	31 0	0·65	164·0
0·125	11·433	1 38	69 32	63 22	30 10	0·575	166·75

TABLE IX.—

1	2	3	4	5	6
TOOL STEEL MAKER	No. of Trial	Front Top Rake t°	Front Clearance C°	Side Top Rake S°	Side Clearance K°
Object of Trial :—To obtain Maximum Cutting Speed					
		Deg. Min.	Deg. Min.	Deg. Min.	
Armstrong, Whitw'th & Co	139	12 41	10 58	6 0	11
Samuel Buckley.....	143	23 38	7 8		9
John Brown & Co.....	133	14 43	11 19	9 55	10
C. Cammell & Co.....	137	14 43	10 37	9 14	3
T. Firth & Sons.....	131	15 23	12 41	16 22	10
Samuel Osborn & Co....	141	13 0	14 2	17 20	12
Seebohm & Dieckstahl ..	135	10 37	13 22	16 42	11
Object of Trial :—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	140	12 0	9 55	5 42	10
Samuel Buckley.....	144	21 49	6 46		8
John Brown & Co.....	134	16 42	8 53	10 58	10
C. Cammell & Co.....	138	16 42	9 55	9 14	13
T. Firth & Sons.....	132	14 2	12 41	17 40	5
Samuel Osborn & Co....	142	12 20	14 2	12 20	12
Seebohm & Dieckstahl ..	136	10 37	13 22	15 23	10
Object of Trial :—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	153	12 0	9 2	5 12	13
Samuel Buckley.....	155	18 0	7 5		7
John Brown & Co.....	145	14 2	14 2	15 30	10
C. Cammell & Co.....	149	7 8	12 58	9 14	10
T. Firth & Sons.....	157	16 3	11 35	18 30	16
Samuel Osborn & Co....	151	11 19	7 25	18 5	6
Seebohm & Dieckstahl ..	147	11 19	6 25	7 28	6
Object of Trial :—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	154	10 37	9 55	14 30	8
Samuel Buckley.....	156	20 34	7 25		8
John Brown & Co.....	146	13 22	10 40	9 52	11
C. Cammell & Co.....	150	7 50	11 20	11 20	9
T. Firth & Sons.....	158	12 41	13 46	19 25	15
Samuel Osborn & Co....	152	10 37	7 25	18 0	6
Seebohm & Dieckstahl ..	148	11 19	8 32	9 14	7

HARD STEEL.

7	8	9	10		11		12		13	14
Height above Centre	Diameter of Work		True Cutting Angle in plane of Shaving $\left(90-(\text{Top rake in this plane} + \beta)\right)$				Angle of plane of shaving		Cutting Arc	Total Weight removed
Z	2 R	β	At Start		At Finish		θ			
for 30 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.										
Inches	Inches	Deg. Min.	Deg.	Min.	Deg.	Min.	Deg.	Min.	Inches.	Lbs.
0·375	13·361	3 14	72	44	64	21	27	12	0·2	21·75
0·375	13·234	3 16	67	26	66	44	36	50	0·22	25·5
0·5	13·888	4 8	68	31	69	49	33	0	0·225	20·25
0·375	13·77	3 7	70	50	72	51	33	0	0·175	14·75
1·0	13·903	8 15	63	45	63	45	30	0	0·26	16·25
0·6875	13·366	5 55	65	25	——		23	38	0·27	21·0
0·375	13·901	3 6	69	54	64	29	31	0	0·16	15·5
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.										
0·375	12·98	3 20	74	21	68	0	32	0	0·35	48·0
0·375	12·837	3 21	65	29	64	14	36	50	0·43	51·25
0·5	13·504	4 15	67	5	——		35	0	0·35	12·0
0·375	13·51	3 11	70	7	68	49	34	0	0·31	32·75
1·0	13·532	8 30	61	30	——		27	45	0·47	48·75
0·625	13·114	5 28	66	12	——		23	38	0·46	36·0
0·4375	13·516	3 42	68	57	68	57	35	0	0·34	20·25
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.										
0·3125	11·32	3 11	74	8	——		25	25	0·4	69·0
0·25	10·2	2 49	69	11	62	21	36	50	0·42	41·25
0·50	12·411	4 37	68	41	——		33	0	0·43	15·5
0·375	12·401	3 28	75	55	——		29	25	0·39	60·5
0·5	10·21	5 37	61	23	——		38	40	0·48	21·75
0·375	12·023	3 35	69	4	——		30	0	0·40	44·75
0·25	12·404	2 18	75	1	75	1	30	0	0·40	23·0
for 30 minutes with $\frac{3}{8}$in. cut by $\frac{1}{8}$in traverse.										
0·3125	10·575	3 24	73	55	67	56	31	0	0·56	92·75
0·25	9·456	3 2	66	58	62	8	36	50	——	90·75
0·5625	12·129	4 51	69	6	——		35	55	0·55	82·75
0·375	10·643	4 3	73	16	71	55	38	40	0·60	90·0
0·5	9·885	5 22	63	28	——		38	40	0·77	86·75
0·25	11·667	2 28	68	52	65	43	38	40	0·65	93·0
0·25	11·40	2 32	73	26	73	26	31	0	0·67	75·0

TABLE X.—

1	2	3	4	5	6
TOOL STEEL MAKER	No. of Trial	Front Top Rake f°	Front Clearance C°	Side Top Rake S°	Side Clearance K°
Object of Trial :—To obtain Maximum Cutting Speed					
		Deg. Min.	Deg. Min.	Deg. Min.	
Armstrong, Whitw'th & Co	167	7 50	9 45	4 0	8
Samuel Buckley.....	165	16 42	8 32		7
John Brown & Co.....	171	13 0	11 35	8 15	11
C. Cammell & Co.	161	16 42	9 5	12 8	7
T. Firth & Sons.....	170	12 0	10 30	15 20	9
Samuel Osborn & Co. ..	163	10 37	6 14	17 14	5
Seebohm & Dieckstahl ..	159	9 55	6 35	4 20	10
Object of Trial :—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	168	8 11	9 45	3 20	10
Samuel Buckley.....	166	18 20	7 25		9
John Brown & Co.....	172	10 37	9 45	9 25	10
C. Cammell & Co.	162	15 23	13 55	11 19	9
T. Firth & Sons	169	15 23	10 46	15 50	12
Samuel Osborn & Co. ..	164	12 0	8 15	17 30	7
Seebohm & Dieckstahl ..	160	7 29	6 0	2 22	7
Object of Trial :—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	182	8 11	7 50	3 15	8
Samuel Buckley.....	177	17 21	7 42		9
John Brown & Co.....	185	12 20	10 28	8 32	12
C. Cammell & Co.	173	11 19	9 45	10 15	8
T. Firth & Sons.....	179	11 40	15 55	19 50	9
Samuel Osborn & Co...	175	14 43	10 46	17 45	8
Seebohm & Dieckstahl ..	186	18 0	3 0	7 8	5
Object of Trial :— To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	183	9 14	8 50	3 5	9
Samuel Buckley.....	178	18 40	7 25		8
John Brown & Co.....	184	16 3	10 10	6 0	10
C. Cammell & Co.	174	10 37	10 46	10 46	8
T. Firth & Sons.....	180	11 40	14 20	15 7	15
Samuel Osborn & Co....	176	13 0	8 32	18 18	5
Seebohm & Dieckstahl ..	187	15 23	4 20	5 10	8

SOFT CAST IRON.

7	8	9	10		11	12		13	14
Height above Centre	Diameter of Work		True Cutting Angle in plane of shaving (90—(Top rake in this plane + β))			Angle of plane of shaving		Cutting Arc	Total Weight removed
Z	2 R	β	At Start		At Finish	θ			
for 30 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.									
Inches	Inches.	Deg. Min.	Deg.	Min.		Deg.	Min.	Inches	Lbs.
0·25	20·311	1 23	80	5		27	10	0·175	37·25
0·375	20·316	2 6	68	17		31	0	0·150	25·5
0·375	19·794	2 11	73	47		23	10	0·22	37·75
0·5	20·829	2 46	67	14		24	50	0·175	39·0
0·5	19·803	2 53	70	25		30	0	0·2	19·0
0·25	20·393	1 25	70	54		37	45	0·2	11·75
0·375	20·828	2 4	77	56		24	50	0·16	38·0
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.									
0·25	19·924	1 30	80	19		32	0	0·4	95·0
0·375	19·915	2 9	66	3		23	10	0·34	26·0
0·375	19·423	2 13	74	47		22	25	0·35	3·0
0·5	20·436	2 49	69	50		39	30	0·35	91·75
0·438	19·916	2 31	67	29		26	0	0·42	108·5
0·375	20·441	2 6	68	36		28	50	0·375	92·25
0·313	20·432	1 45	79	43		31	0	0·35	76·25
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.									
0·375	17·2	2 30	78	37		24	50	0·45	131·5
0·25	18·345	1 34	68	26		26	35	0·47	116·25
0·25	16·113	1 48	74	10		17	20	0·4	98·5
0·5	19·534	2 53	73	25		24	10	0·4	93·0
0·625	18·313	3 56	66	4		31	0	0·52	126·25
0·375	19·417	2 14	67	46		27	10	0·42	125·25
0·25	15·687	1 50	72	47		21	49	0·45	86·75
for 30 minutes with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.									
0·188	16·466	1 18	79	28		33	0	0·6	223·75
0·25	17·546	1 38	67	48		33	32	0·65	215·5
0·188	16·858	1 16	76	24		31	0	0·66	209·0
0·5	18·84	3 3	71	34		40	0	0·6	186·0
0·625	17·583	4 4	69	14		30	0	0·67	220·0
0·375	18·679	2 18	67	8		33	0	0·62	201·0
0·125	14·914	0 58	78	35		31	0	0·67	219·75

TABLE XI.—

1	2	3		4		5		6
TOOL STEEL MAKER	No. of Trial	Front Top Rake		Front Clearance		Side Top Rake		Side Clearance
		$t°$		$C°$		$S°$		$K°$
Object of Trial :—To obtain Maximum Cutting Speed								
		Deg.	Min.	Deg.	Min.	Deg.	Min.	
Armstrong, Whitw'th & Co	52	9	14	5	21	1	30	8
Samuel Buckley	42	17	21	5	43	——		9
John Brown & Co.....	50	9	14	8	36	7	48	11
C. Cammell & Co.	54	16	3	10	37	11	19	7
T. Firth & Sons	46	9	55	9	35	12	0	8
Samuel Osborn & Co. ..	44	9	14	8	35	9	12	11
Seebohm & Dieckstahl ..	48	9	55	8	54	4	18	8
Object of Trial :—To obtain Maximum Cutting Speed								
Armstrong, Whitw'th & Co	53	11	39	4	45	1	5	5
Samuel Buckley	43	17	20	8	11	——		8
John Brown & Co.....	51	10	37	8	36	6	45	9
C. Cammell & Co.	55	15	23	9	56	7	50	4
T. Firth & Sons	47	12	42	11	30	11	30	11
Samuel Osborn & Co. ..	45	9	14	8	54	9	12	7
Seebohm & Dieckstahl ..	49	14	2	7	48	5	45	6
Object of Trial :—To obtain Maximum Cutting Speed								
Armstrong, Whitw'th & Co	58	9	55	6	35	3	43	7
Samuel Buckley	64	14	43	7	8	——		7
John Brown & Co.....	60	7	29	7	6	5	42	11
C. Cammell & Co.....	56	12	0	10	37	0	0	8
T. Firth & Sons	62	15	23	12	40	16	3	8
Samuel Osborn & Co. ..	68	9	14	6	27	18	0	4
Seebohm & Dieckstahl ..	66	17	21	9	14	14	2	7
Object of Trial :—To obtain Maximum Cutting Speed								
Armstrong, Whitw'th & Co	59	7	50	5	10	2	0	10
Samuel Buckley	65	11	40	8	35	——		8
John Brown & Co.....	61	12	0	12	0	5	42	10
C. Cammell & Co.	57	12	41	14	3	3	35	7
T. Firth & Sons	63	11	19	12	0	14	43	9
Samuel Osborn & Co. ..	69	9	55	7	8	15	22	4
Seebohm & Dieckstahl ..	67	14	43	9	14	13	42	8

MEDIUM CAST IRON.

7	8	9	10	11	12	13	14
Height above Centre	Diameter of Work		True Cutting Angle in plane of shaving $\left(90-(\text{Top rake in this plane} + \beta)\right)$		Angle of plane of shaving	Cutting Arc	Total Weight removed
Z	2 R	β	At Start	At Finish	θ		
for 30 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.							
Inches	Inches.	Deg Min.	Deg. Min.		Deg. Min.	Inches	Lbs.
On centre	16·592		80 46		21 49	0·2	18·25
0·75	17·817	4 50	67 10		36 50	0·12	19·25
0·5	16·730	3 26	75 57		25 25	0·15	7·0
0·625	16·478	4 20	66 22		26 0	0·16	8·5
0·563	17·314	3 44	73 35		23 10	0·25	13·0
0·813	17·844	5 14	72 46		26 35	0·20	1·0
0·375	17·215	2 30	76 53		18 0	0·17	20·75
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.							
On centre	17·626		79 23		24 10	0·4	38·5
0·75	17·449	4 56			36 50	0·33	52·0
0·5	17·586	3 16	69 44		26 35	0·32	1.75
0·625	16·244	4 23	68 55		27 10	0·4	9·5
0·5	17·606	3 14	71 22		26 35	0·4	12·0
0·75	17·632	4 52	73 8		23 38	0·38	12·75
0·375	16·846	2 33	74 5		23 38	0·36	30·75
for 30 minutes with $\frac{1}{8}$in. cut by $\frac{1}{8}$in. traverse.							
0·125	16·23	0 52	79 13		31 0	0·45	67·0
0·125	15·502	0 56	71 43		33 0	0·4	4·25
0·219	15·9	1 44	80 5		27 45	0·4	18·5
0·625	17·678	4 4	78 6		27 45	0·3	57·25
0·5	15·884	3 36	68 24		18 0	0·45	58·0
0·25	15·088	1 54	75 25		21 49	0·375	40·75
0·25	15·51	1 51	68 9		17 21	0·33	28·0
for 30 minutes with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.							
0·125	16·856	0 5 1	81 19		23 10	0·61	46·5
0·125	16·053	0 54	70 6		37 45	0·66	99·5
0·282	16·9	1 54	75 25		30 0	0·61	26·0
0·625	16·841	4 17	73 43		33 0	0·5	21·75
0·75	16·756	5 8	67 31		29 25	0·64	88·5
0·125	15·398	0 56	73 1		33 0	0·56	17·0
0·25	15·447	1 57	70 42		27 10	0·53	23·75

TABLE XII.—

1	2	3	4	5	6
TOOL STEEL MAKER.	No. of Trial	Front Top Rake $t°$	Front Clearance ($C°$)	Side Top Rake $S°$	Side Clearance $K°$
Object of Trial:—To obtain Maximum Cutting Speed					
		Deg. Min.	Deg. Min.	Deg. Min.	
Armstrong, Whitw'th & Co	107	6 25	8 32	2 50	11
Samuel Buckley.....	190	13 22	7 28	——	8
John Brown & Co.....	113	11 19	11 19	5 43	11
C. Cammell & Co.....	109	12 20	9 56	7 50	12
T. Firth & Sons.....	117	9 14	11 19	11 19	8
Samuel Osborn & Co. ..	121	12 20	7 50	14 3	5
Seebohm & Dieckstahl ..	111	9 55	9 56	8 10	9
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	108	13 22	9 56	1 5	11
Samuel Buckley	191	12 41	7 28	——	8
John Brown & Co.....	114	11 19	11 19	7 8	10
C. Cammell & Co.....	110	11 40	19 20	14 40	8
T. Firth & Sons	120	12 0	14 3	18 0	9
Samuel Osborn & Co. ..	122	8 28	10 37	18 40	9
Seebohm & Dieckstahl ..	112	12 0	9 56	6 5	13
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	125	9 14	8 32	2 50	8
Samuel Buckley.....	189	13 0	7 28	——	9
John Brown & Co.....	115	9 55	14 3	6 5	11
C. Cammell & Co.....	129	13 42	11 19	9 56	10
T. Firth & Sons...	118	14 43	11 39	13 42	7
Samuel Osborn & Co. ..	124	11 40	8 32	16 3	8
Seebohm & Dieckstahl ..	127	10 37	10 37	10 16	9
Object of Trial:—To obtain Maximum Cutting Speed					
Armstrong, Whitw'th & Co	126	8 32	7 50	0 0	10
Samuel Buckley.....	188	14 2	7 28	——	8
John Brown & Co.....	116	12 41	12 41	7 8	10
C. Cammell & Co.....	130	5 42	10 58	9 14	14
T. Firth & Sons.....	119	12 20	9 56	15 25	8
Samuel Osborn & Co. ..	123	12 20	5 43	18 0	3
Seebohm & Dieckstahl ..	128	8 53	7 8	8 32	8

HARD CAST IRON.

7	8	9	10	11	12	13	14
Height above Centre.	Diameter of Work		True Cutting Angle in plane of Shaving (90—(Top rake in this plane + β))		Angle of plane of shaving.	Cutting Arc	Total Weight removed
Z	2 R	β	At Start	At Finish	θ		
for 30 minutes with $\frac{1}{16}$in. cut by $\frac{1}{16}$ in. traverse.							
Inches	Inches	Deg. Min.	Deg. Min.	Deg. Min.	Deg. Min.	Inches	Lbs.
On centre	11·854	——	83 35		32 30	0·25	12·875
0·125	7·079	2 3	71 15		20 0	0·15	4·75
0·25	11·353	2 32	74 47		26 35	0·2	14·5
0·125	11·857	1 14	73 43		32 0	0·12	14·0
0·25	10·998	2 37	75 3		30 0	0·2	13·25
0·0625	10·635	0 41	72 37		28 15	0·22	12·875
0·125	11·857	1 14	76 46		24 10	0·2	14·0
for 30 minutes with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.							
On centre	11·478	——	82 10		40 20	0·375	33·5
On centre	6·876	——	75 38		24 50	0·5	28·0
0·25	11·024	2 37	75 23		21 49	0·4	28·75
0·188	11·482	1 52	73 46		40 20	0·35	35·5
0·313	10·271	3 32	70 25		20 34	0·425	14·75
0·063	10·17	0 44	71 35		36 0	0·5	30·0
0·125	11·499	1 15	75 23		33 0	0·36	31·25
for 60 minutes with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.							
On centre	9·774	——	80 46		38 40	0·41	88·0
0·125	7·488	1 55	72 2		20 34	0·54	63·25
0·25	11·128	2 35	77 10		33 32	0·38	81·5
0·063	8·824	0 49	74 8		15 23	0·52	85·25
0·313	10·66	3 24	67 18		27 45	0·42	97·25
0·063	9·805	0 44	73 13		21 49	0·52	23·125
0·063	9·466	0 46	76 33		23 10	0·39	85·75
for 30 minutes with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.							
On centre	8·654	——	82 35		38 40	0·675	76·0
0·25	7·93	3 37	70 20		24 10	0·875	61·25
0·25	10·264	2 28	74 20		31 0	0·61	71·75
0·063	7·234	——	77 40		40 20	0·66	76·25
0·313	9·529	3 46	68 33		32 0	0·61	96·0
On centre	——	——	71 40		40 0		——
0·063	7·96	0 55	76 45		33 0	0·675	79·5

TABLE XIII.—SOFT STEEL.

1	2	3	4	5	6	7	8	9	10	11
Tool Steel Maker	No. of Trial	Horse Power Electrically Measured			† Corrected Net	Average Cutting Speed	Cutting Force on Point of Tool	Area of Cut	Mean Revs. of Motor	Gear and Cone Step in use
		Gross	Lost	Net						
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.										
						Ft. per min	Lbs.	Sq. in.	P. min	*
A. W.	1	16·1	13·70	2·4		193·0	410	0·00338	260	Ds.
Bu ..	9	12·03	9·92	2·11		106·0	657	0·00365	224	Dm.
Br ..	7	———	——Not	Taken—	———	163·5	———	0·00381	220	Ds.
Ca...	13	15·65	11·94	3·71		149·2	821	0·00325	215	,,
Fi. ..	5	14·07	9·40	4·67		128·0	1,210	0·00367	260	Dm.
Os ..	3	13·00	9·37	3·63		114·0	1,050	0·00344	224	,,
S. D.	15	14·80	10·45	4·35		124·5	1,150	0·00372	258	,,
V. M.	11	16·30	12·82	3·48		132·5	867	0·00362	288	,,
Average		14·58				138·8	881	0·00357		
							110 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.										
A. W.	2	18·90	9·80	9·10		111·0	2,705	0·01060	220	Dm.
Bu ..	10	18·30	9·60	8·70		108·0	2,660	0·01058	228	,,
Br ..	8	17·45	10·45	7·00		98·6	2,440	0·01280	230	,,
Ca...	14	21·80	10·75	11·05		121·0	3,020	0·01096	252	,,
Fi. ..	6	17·25	10·12	7·13		93·5	2,522	0·01018	255	Dl.
Os ..	4	14·76	8·36	6·40		83·0	2,543	0·01038	231	,,
S. D.	16	15·75	8·00	7·75		100·9	2,530	0·01060	210	Dm.
V. M.	12	19·40	10·24	9·16		106·4	2,840	0·01040	225	,,
Average		17·95				102·8	2,658	0·01081		
							110 tons per sq. in.			
Object of Trial:- -To obtain Maximum Cntting Speed with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	38	18·50	6·74	11·76		74·00	5,240	0·02150	190	Dm.
Bu ..	31	14·88	7·71	7·17		38·73	6,110	0·02260	250	Tm.
Br ..	40	16·10	7·16	8·94		63·50	4,650	0·01990	220	Dl.
Ca...	29	21·05	10·54	10·51		61·06	5,680	0·01990	264	Ts.
Fi. ..	35	17·90	7·12	10·78		66·60	5,425	0·02155	220	Dl.
Os ..	27	21·00	8·60	12·40		72·88	5,620	0·02035	225	,,
S. D.	33	20·20	10·50	9·70		52·20	6,130	0·01850	258	Ts.
V. M.		Retired	from	Trials						
Average		18·52				61·28	5,551	0·02061		
							120 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	39	28·30	12·250	16·050		54·50	9,720	0·04010	210	Dl.
Bu ..	32	19·30	7·970	11·330		28·96	12,920	0·04630	260	Tl.
Br ..	41	26·00	9·275	16·725		50·75	10,860	0·04340	265	Ts.
Ca...	30	25·20	8·010	17·190		37·35	15,200	0·04625	240	Tm.
Fi. ..	36	26·20	10·460	15·740		52·50	9,900	0·03680	250	Ts.
Os ..	28	23·10	8·250	14·850		49·30	9,960	0·04040	220	,,
S. D.	34	24·45	8·640	15·810		38·30	13,625	0·04230	260	Tm.
V. M.										
Average		24·65				44·52	11,740	0·04222		
							124 tons per sq. in.			

* D = Double Gear T = Treble Gear

s = Small
m = Middle
l = Large
} Cone Step

† Regarding these corrections see page 248

TABLE XIV.—MEDIUM STEEL.

1	2	3	4	5	6	7	8	9	10	11
Tool Steel Maker	No. of Trial	Horse Power Electrically Measured: Gross	Lost	Net	Corrected Net	Average Cutting Speed	Cutting Force on Point of Tool	Area of Cut	Mean Revs. of Motor	Gear and Cone Step in use
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.										
						Ft. per min	Lbs.	Sq. in.	P. min	
A. W.	79	11·120	8·40	2·720	2·125	109·0	643	0·00225	250	Dm.
Bu..	91	11·360	7·73	3·630	2·710	105·0	853	0·00384	270	,,
Br...	83	9·575	6·455	3·140	3·140	102·0	1,015	0·00397	232	,,
Ca...	89	11·150	7·640	3·510	3·095	104·5	977	0·00375	265	,,
Fi...	81	12·520	9·190	3·330	3·145	105·2	985	0·00390	238	,,
Os..	87	11·900	8·850	3·050	2·525	93·0	898	0·00384	300	,,
S. D.	85	10·025	6·600	3·425	3·130	93·5	1,105	0·00378	225	,,
Average		11·097				101·7	925	0·00362		
							114 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.										
A. W.	80	13·48	8·160	5·32		67·5	2,600	0·01190	215	Dl.
Bu. .	92	12·10	6·550	5·55		89·5	2,047	0·01220	215	Dm.
Br...	84	15·50	9·660	5·84		74·7	2,580	0·01148	252	Dl.
Ca...	90	14·40	7·720	6·68		80·0	2,755	0·01140	226	Dm.
Fi...	82	15·98	10·270	5·71		81·6	2,307	0·01162	250	Dl.
Os...	88	13·90	8·500	5·40		70·5	2,530	0·01120	240	Dm.
S. D.	86	13·69	7·160	6·53		66·5	3,250	0·01150	230	Dl.
Average		14·15				75·8	2,581	0·01161		
							99·3 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	95	19·22	9·94	9·28	9·0	48·5	6,125	0·02140	254	Ts.
Bu...	94	17·20	8·83	8·37		54·1	5,100	0·02250	280	,,
Br.	99	18·00	9·65	8·35		49·4	5,570	0·02150	276	,,
Ca...	102	15·91	6·72	9·19		61·2	4,955	0·02290	200	Dm.
Fi...	97	19·10	10·55	8·55		51·5	5,480	0·02270	280	Ts.
Os...	103	14·70	6·75	7·95		49·9	5,250	0·02175	235	Dl.
S. D.	105	16·10	7·00	9·10		51·4	5,850	0·02275	230	,,
Average		17·176				52·3	5,480	0·02222		
							110 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	96	20·45	7·38	13·07		39·0	11,050	0·04180	214	Ts.
Bu..	93	19·00	7·65	11·35		36·0	10,460	0·04365	260	Tm.
Br...	100	19·90	7·63	12·27		37·9	10,680	0·04325	220	Ts.
Ca...	101					38·5		0·04120	200	Dl.
Fi...	98	18·80	7·42	11·38		36·6	10,250	0·04080	205	Ts.
Os...	104	18·75	6·90	11·85		37·5	10,400	0·04320	213	,,
S. D.	106	21·16	9·65	11·51		38·6	9,840	0·04250	270	,,
Average		19·78				37·7	10,446	0·04234		
							110·2 tons per sq. in.			

TABLE XV.—HARD STEEL.

1	2	3	4	5	6	7	8	9	10	11
Tool Steel Maker	Number of Trial	Horse Power Electrically Measured				Average Cutting Speed	Cutting Force on Point of Tool	Area of Cut	Mean Revs. of Motor	Gear and Cone Step in use
		Gross	Lost	Net	Corrected Net					
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.										
						Ft. per min	Lbs.	Sq. in.	P. min	
A. W.	139	9·30	7·10	2·20	1·685	52·50	1,172	0·00397	220	Dl.
Bu ..	143	10·25	8·10	2·15	2·150	59·50	1,190	0·00412	250	,,
Br ..	133	12·45	10·03	2·42	1·845	49·75	1,225	0·00390	285	Ts.
Ca...	137	11·10	8·28	2·82	2·610	58·00	1,488	0·00362	240	Dl.
Fi...	131	13·60	10·24	3·36	2·100	46·80	1,480	0·00328	270	Ts.
Os ..	141	10·50	7·87	2·63	2·075	56·20	1,218	0·00381	235	Dl.
S. D.	135	13·24	9·45	3·79	2·905	59·10	1,620	0·00359	250	,,
Average						54·5	1,342	0·003744		
							160 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.										
A. W.	140	13·13	8·370	4·76		40·0	3,925	0·0119	240	Ts.
Bu ..	144	13·80	8·70	5·10		41·2	4,080	0·0124	250	Dl.
Br ..	134	13·66	8·88	4·78		42·5	3,720	0·0120	244	Ts.
Ca...	138	13·10	8·10	5·00		40·5	4,075	0·01173	240	,,
Fi ..	132	12·95	9·300	3·65		40·6	2,970	0·0117	230	,,
Os ..	142	13·15	8·10	5·05		38·8	4,340	0·0117	240	,,
S. D.	136	15·19	10·05	5·14		43·5	3,900	0·0116	250	,,
Average						41·0	3,858	0·01186		
							145·5 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	153	15·30	7·87	7·43		30·8	7,960	0·0219	215	Ts.
Bu ..	155	14·60	8·40	6·20		30·7	6,664	0·02345	235	,,
Br...	145	16·80	9·65	7·15		31·9	7,400	0·0234	204	,,
Ca...	149	15·90	8·05	7·85		32·6	7,950	0·0229	205	,,
Fi...	157	14·68	8·78	5·90		30·0	6,490	0·02265	230	,,
Os...	151	12·70	6·55	6·15		29·9	6,800	0·0230	194	,,
S. D.	147	12·55	6·20	6·35		26·8	7,850	0·0239	178	
Average						30·4	7,302	0·0230		
							142·3 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	154	16·68	7·00	9·68		20·8	15,357	0·0452	230	Tm.
Bu ..	156	14·60	7·00	7·60		18·7	13,412	0·0464	229	,,
Br...	146	17·80	7·30	10·50		20·0	17,300	0·0410	200	Tl.
Ca...	150	15·90	6·95	8·95		20·0	14,800	0·0441	210	Tm.
Fi...	158	16·40	6·87	9·53		20·0	15,724	0·0429	235	,,
Os...	152	14·50	6·30	8·20		20·15	13,300	0·0452	200	,,
S. D.	148	16·40	7·52	8·88		17·60	16,650	0·0415	247	Tl.
Average						19·61	15,220	0·0438		
							155·2 tons per sq. in.			

TABLE XVI.—SOFT CAST IRON.

1	2	3	4	5	6	7	8	9	10	11
Tool Steel Maker	Number of Trial	Horse Power Electrically Measured				Average Cutting Speed	Cutting Force on Point of Tool	Area of Cut	Mean Revs. of Motor	Gear and Cone Step in use
		Gross	Lost	Net	Corrected Net					
Object of Trial;—To obtain Maximum Cutting Speed with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.										
						Ft. per min	Lbs.	Sq. in.	P. min	
A. W.	167	8·76	7·15	1·61	1·330	101·5	432	0·00409	105	Dm.
Bu ..	165	9·25	7·40	1·85	1·645	112·0	485	0·00375	215	,,
Br ..	171	9·06	6·95	2·11	1·940	107·0	598	0·00397	220	,,
Ca...	161	9·77	7·45	2·32		109·0	700	0·00390	215	,,
Fi...	170	9·35	7·20	2·15		107·0	665	0·00400	215	,,
Os ..	163	12·50	9·67	2·83	1·980	103·5	631	0·00118	218	,,
S. D.	159	10·40	9·40	1·00	0·725	103·5	225	0·00394	202	,,
Average		9·87				106·2	534	0·00355		
							67·2 tons per sq. in			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.										
A. W.	168	10·10	7·90	2·20		89·0	815	0·0124	180	Dm.
Bu ..	166	9·75	6·93	2·82		80·2	1,160	0·0123	230	Dl.
Br ..	172	12·40	4·13	Not	Taken	89·0	——	0·0116		Dm.
Ca...	162	10·60	8·06	2·54		82·1	1,020	0·0122	225	Dl.
Fi...	169	10·85	7·17	3·68		99·5	1,220	0·0124	225	Dm.
Os ..	164	11·90	9·00	2·90		84·7	1,130	0·0121	235	Dl.
S. D.	160	13·40	10·75	2·65	2·30	71·0	1,070	0·0124	275	Ts.
Average		11·29				85·1	1,069	0·01221		
							39·1 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	182	12·09	7·05	5·85		66·2	2,920	0·02140	215	Dl.
Bu ..	177	11·35	6·90	4·45		62·0	2,370	0·02130	1 0	,,
Br ..	185	11·90	6·75	5·15		61·5	2,760	0·01890	215	,,
Ca...	173	13·70	7·95	5·75		72·0	2,640	0·01575	205	,,
Fi...	179	10·50	5·66	4·84		64·0	2,500	0·02280	190	,,
Os	175	11·80	8·00	3·80		58·2	2,160	0·02370	235	Ts.
S. D.	186	11·70	6·90	4·80		60·9	2,600	0·02140	210	Dl.
Average		11·98				63·5	2,564	0·02075		
							55·1 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	183	14·70	6·37	8·33		55·50	4,959	0·0459	190	Dl.
Bu ..	178	13·20	7·90	5·30		49·00	3,570	0·0474	220	Ts.
Br ..	184	15·00	6·66	8·34		53·00	5,200	0·0420	185	Dl.
Ca...	174	11·90	6·75	5·15		43·80	3,880	0·0460	185	Ts.
Fi...	180	13·70	4·95	8·75		53·20	5,420	0·0462	240	,,
Os ..	176	12·20	6·85	5·35		48·50	3.650	0·0460	205	,,
S. D.	187	12·27	5·71	6·56		52·25	4,150	0·0455	200	,,
Average		13·28				50·75	4,403	0·0456		
							43·5 tons per sq. in.			

TABLE XVII.—MEDIUM CAST IRON.

1	2	3	4	5	6	7	8	9	10	11
Tool Steel Maker	Number of Trial	Horse Power Electrically Measured: Gross	Lost	Net	Corrected Net	Average Cutting Speed	Cutting Force on Point of Tool	Area of Cut	Mean Revs. of Motor	Gear and Cone Step in use
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.										
						Ft. per min	Lbs.	Sq. in.	P. min	
A. W.	52	10·10	8·5	1·65	1·365	50·70	890	0·00881	242	Ts.
Bu ..	42	8·81	7·58	1·23	0·955	51·80	608	0·00350	230	,,
Br ..	50	7·91	5·71	2·00		62·00	1,064	0·00290	205	Dl.
Ca.	54	9·05	7·32	1·83		68·50	882	0·00350	230	,,
Fi...	46	10·64	9·22	1·42	1·410	56·88	815	0·00393	265	Ts.
Os ..	44	9·50				69·00		0·00313	218	Dl.
S. D.	48	12·40	10·23	2·17	1·730	59·70	956	0·00331	275	Ts.
Average		9·77				59·8	869	0·00347		
							112 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.										
A. W.	53	11·46	8·32	3·14		40·30	2,570	0·0099	264	Tm.
Bu ..	43	9·38	7·12	2·26		49·00	1,520	0·0115	220	Ts.
Br ..	51	8·90	7·37	1·53		48·80	1,034	0·0110	214	,,
Ca ..	55	10·90	8·00	2·89		50·20	1,870	0·0109	235	,,
Fi...	47	9·19	6·65	2·54		44·24	1,895	0·0105	200	Tl.
Os ..	45	10·75	8·73	2·02		49·80	1,340	0·0097	226	Ts.
S. D.	49	11·62	8·50	3·13		51·20	2,022	0·0108	240	,,
Average		10·31				47·7	1,750	0·0106		
							78·7 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	58	10·1	6·55	3·55		33·10	3,530	0·0227	227	Tm.
Bu ..	64	11·76	8·44	3·32		50·00	2,190	0·0221	256	Ts.
Br ..	60	9·65	6·11	3·54		30·30	3,855	0·0203	215	Tm.
Ca...	56	11·95	8·34	3·61		31·90	3,730	0·0175	280	Tl.
Fi...	62	12·55	7·90	4·65	3·975	34·40	3,800	0·0219	235	Tm.
Os ..	68	13·15	8·95	4·20	3·940	34·40	3,765	0·0223	260	,,
S. D.	66	11·90	8·30	3·60		36·60	3,245	0·0219	270	,,
Average		11·58				35·80	3,445	0·0213		
							72·5 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{4}$in. traverse.										
A. W.	59	15·19	8·08	7·11		27·70	8,470	0·0373	260	Tl.
Bu ..	65	11·59	7·27	4·32		24·35	5,860	0·0446	240	,,
Br ..	61	13·54	7·18	6·36		25·20	8,330	0·0351	235	,,
Ca...	57	12·50	7·38	5·12		25·60	6,600	0·0401	240	,,
Fi...	63	10·62	6·48	4·14		22·00	6,210	0·0440	206	,,
Os ..	69	14·10	8·59	5·51		25·10	7,240	0·0407	257	,,
S. D.	67	13·17	7·60	5·57		25·40	7,240	0·0377	258	Tm.
Average		12·96				25·00	7,186	0·0399		
							80 tons per sq. in.			

TABLE XVIII.—HARD CAST IRON.

1	2	3	4	5	6	7	8	9	10	11
Tool Steel Maker	Number of Trial	Horse Power Electrically Measured				Average Cutting Speed	Cutting Force on Point of Tool	Area of Cut	Mean Revs. of Motor	Gear and Cone Step in use
		Gross	Lost	Net	Corrected Net					
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{1}{16}$in. cut by $\frac{1}{16}$in. traverse.										
						Ft. per min	Lbs.	Sq. in.	P. min	
A. W.	107	11·67	9·88	1·79	1·080	36·4	980	0·00369	240	Ts.
Bu...	190	9·39	8·20	1·19	0·99	31·1	1,050	0·00398	250	Dl.
Br...	113	12·96	10·64	2·30	0·825	38·5	715	0·00375	270	Ts.
Ca...	109	11·15	9·65	1·50	0·525	38·6	450	0·00359	255	,,
Fi ..	117	11·36	9·17	2 19	1·190	36·0	1,085	0·00390	260	,,
Os...	121	11·90	9·70	2·20	1·710	37·5	1,500	0·00343	280	,,
S. D.	111	10·25	8·5	1·75	1·15	38·4	985	0·00378	250	,,
Average		11·24				36·65	966·4	0·00374		
							115 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{16}$in. traverse.										
A. W.	108	9·32	7·83	1·49		30·3	1,620	0·01173	210	Ts.
Bu...	191	8·15	6·73	1·42		26·7	1,750	0·01048	210	Dl.
Br...	114	10·20	7·72	2·48		30 5	2,680	0·01010	220	Ts.
Ca...	110	9·42	8·14	1·28		31·9	1,324	0·01173	242	,,
Fi...	120	9·65	8·20	1·45		31·8	1,500	0·01155	240	,,
Os...	122	9·50	7·64	1·86		29·5	2,080	0·01061	230	,,
S. D.	112	9·00	6·63	2·37		30·1	2,600	0·01119	210	,,
Average		9·32				30·1	1,936	0·01105		
							78 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{16}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	125	11·33	7·98	3·35	2·55	21·00	4,010	0·02345	240	Tm.
Bu.	189	10·20	7·68	2·52		20·80	3,998	0·01725	225	Ts.
Br...	115	9·50	6·75	2·75	2·02	20·20	3,300	0·02155	205	Tm.
Ca...	129	10·05	7·10	2·95		25·00	3,930	0·02025	230	Ts.
Fi...	118	11·20	8·66	2·54		24·70	3,393	0·02112	260	Tm.
Os...	124	9·52	7·52	2·00		20·10	3,290	0·02175	234	,,
S. D.	127	10·22	7·22	3·00		24·75	4,000	0·01912	210	Ts.
Average		10·29				22·36	3,703	0·02064		
							80 tons per sq. in.			
Object of Trial:—To obtain Maximum Cutting Speed with $\frac{3}{8}$in. cut by $\frac{1}{8}$in. traverse.										
A. W.	126	11·10	7·61	3·49		18·00	5,450	0·0457	232	Tm.
Bu...	188	10·50	6·74	3·76		18·45	6,730	0·0363	180	Ts.
Br...	116	8·25	5·92	2·33		17·20	4,480	0·0448	190	Tm.
Ca...	130	12·15	8·85	3·30		19·10	5,700	0·0426	280	,,
Fi...	119	11·60	8·60	3·00		22·00	4,500	0·0459	260	,,
Os...	123									
S. D.	128	12·50	9·06	3·44		19·50	5,800	0·0441	270	Ts.
Average		11·02				19·00	5,443	0·0432		
							56·4 tons per sq. in.			

TABLE XX.—ENDURANCE

Intended length of run: Two hours.

No. of Trial	Description of Tool Steel used	Intended Speed Ft. per min.	Actual Speed	Actual Cut	Actual Traverse	Area of Section of Cut	Duration of Trial
191	High-speed Air Hardened	90	93·0	0·183	0·0625	0·01143	120·0
194	Do. do.	90	89·8	0·191	0·0625	0·01193	64·87
*195	Do. do.	90	89·0	0·1875	0·0625	0·01172	16·73
197	Do. do.	90	90·5	0·188	0·0625	0·01175	120·0
198	Do. do.	90	97·0	0·190	0·0625	0·01187	120·0
199	Do. do.	90	87·7	0·190	0·0625	0·01187	14·82
200	Do. do.	90	90·0	0·187	0·0625	0·01168	120·0
*201	Do. do.	90	92·0	0·185	0·0625	0·01155	16·73
	Averages....					0·01172	
196	Ordinary Mushet	45	43·0	0·192	0·0625	0·01199	78·83
192	Ordinary Water Hardened	22½	24·0	0·175	0·0625	0·01093	9·117
193	Do. do.	22½	22·8	0·174	0·0625	0·01087	28·6
202	Do. do.	22½	23·0	0·190	0·0625	0·01187	10·6
203	Do. do.	22½	22·5	0·188	0·0625	0·01175	23·6

*201 same Tool as 195 reforged and tempered and tried again.

TABLE XXI.—ENDURANCE TRIALS

Intended length of run: Two hours.

204	High-speed Air Hardened	44	42·3	0·189	0·0625	0·01181	10·0
205	Do. do.	40	39·0	0·189	0·0625	0·01181	31·0
209	Do. do.	40	36·2	0·1875	0·0625	0·01171	6·0
210	Do. do.	40	39·0	0·1875	0·0625	0·01171	9·0
211	Do. do.	36	34·4	0·181	0·0635	0·01130	69·0
212	Do. do.	36	33·8	0·1875	0·0625	0·01171	3·5
213	Do. do.	36	34·2	0·1875	0·0625	0·01171	2·15
214	Do. do.	36	34·2	0·1875	0·0625	0·01171	60·0
215	Do. do.	36	33·7	0·185	0·0625	0·01156	19·0
216	Do. do.	36	34·2	0·1875	0·0625	0·01171	3·0
217	Do. do.	36	35·2	0·1875	0·0625	0·01171	1·73
218	Do. do.	36	35·1	0·178	0·0625	0·01112	62·0
219	Do. do.	36	35·5	0·179	0·0625	0·01118	33·0
	Averages....					0·01159	
208	Ordinary Mushet	20	19·5	0·189	0·0625	0·01181	60·0
208a	Do.	25	22·5	0·1875	0·0625	0·01171	5¼
206	Ordinary Water Hardened	12½	12·0	0·189	0·0625	0·01181	3·45
207	Do. do.	12½	10·3	0·189	0·0625	0·01181	9·0

TRIALS ON SOFT STEEL.

Intended cut, $\frac{3}{16}$in.; traverse, $\frac{1}{16}$in.

Reason for Stopping	Area Machined in square feet		Weight removed in lbs.		Gross E.H.P.	Friction H.P.	Net H.P.	Cutting Force lbs.	Motor Speed Gear and Cone Step
	Total	Per min	Total	Per min					
Time up	58·0	0·483	451½	3·76	12·93	5·92	7·01	2,856	170
Tool failed	30·3	0·466	236	3·64	17·15	8·88	8·27	3,080	250
do.	7·73	0·462	57⅜	3·45	17·10	9·4	7·70	2,920	250
Time up	56·54	0·471	431	3·59	16·64	9·46	7·18	2,620	270 Dm.
do.	59·70	0·4975	460¼	3·84	15·36	8·26	7·10	2,440	210 Ds.
Tool failed	6·76	0·456	50	3·37	14·40	8·64	5·76	2,170	200
Time up	52·32	0·463	425·5	3·55	14·50	8·38	6·12	2,250	205 Ds.
Tool failed	8·02	0·479	60	3·58	18·90	10·43	8·47	3,040	215
								2,609	=98·5 tons per sq. in.
Tool failed	17·84	0·226	136¾	1·735	10·8	6·46	4·34	3,100	
do.	1·14	0·125	8½	0·905	15·2?	9·03?	6·17?	8,480?	250
do.	3·395	0·119	21½	0·858	11·15	9·03	2·12	3,050	250
do.	1·265	0·119	9	0·85	10·9	8·25	2·65	3,800?	220 Tm.
do.	2·76	0·117	20½	0·87	10·35	7·38	2·97	4,350?	222

ON MEDIUM CAST IRON.

Intended cut, $\frac{3}{16}$in.; traverse $\frac{1}{16}$in.

Tool failed	2·20	0·220	14½	1·425	11·22	7·82	3·40	2,650	215 Ts.
do.	6·29	0·203	43¾	1·44	9·63	7·17	2·46	2,075	200 ,,
do.	1·13	0·190	6¾	1·08	11·60	8·30	3·30	3,100	205 ,,
do.	1·83	0·203	11½	1·28	9·90	7·75	2·15	1,820?	202 ,,
do.	12·50	0·181	82	1·19	11·45	8·23	3·22	3,082	260 Tm.
do.	0·615	0·176	2⅞	0·822	10·72	8·23	2·49	2,430	260 ,,
do.	0·40	0·186	1⅝	0·813	10·60	8·40	2·20	2,120	260 ,,
do.	10·66	0·177	73⅝	1·225	10·83	7·92	2·91	2,340	263 ,,
do.	3·34	0·176	22⅜	1·18	10·4	7·5	2·90	2,840	260 ,,
do.	·53	0·178	3	1·0	10·7	8·2	2·5	2,410	260 ,,
do.	·32	0·183	1¼	0·72	14·0	11·15	2·25	2,680	270 ,,
do.	11·40	0·184	75¾	1·22	12·3	8·7	3·6	3,380?	275 ,,
do.	6·12	0·185	39⅓	1·20	11·6	9·0	2·6	2,420	284 ,,
								2,565	= 99 tons per sq. in.
End of run	6·1	0·106	41½	0·69	7·75	6·2	1·55	2,620	200 Tl.
Tool failed	·63	0·115	3¾	0·681	9·8	8·4	1·4	2,050	260 ,,
do.	·215	0·062	¼	0·072					152 ,,
do.	·485	0·054	2¾	0·30	5·67	4·53	1·14	3,650?	140 ,,

TABLE XXIII.—HARDNESS TESTS.

No. of Trial	Time	Duration	Counter Readings	Total Revolutions	Height of Drill	Figure of Hardness *	
		Min. Sec.					
1	2-40-35		822		4·485	4·74	
	2-41-27	0 52	1,059	237	3·985		Standard Specimen
2	2-58-3		545	192	4·485		
	2-58-42	0 39	737		3·985	3·84	Whitworth's Soft Cast Iron
3	3-4-7		82		4·485		
	3-5-0	0 53	333	251	3·985	5·02	Whitworth's Medium Cast Iron
4	2-13-55		692		4·485		
	2-14-45	0 50	943	251	3·985	5·02	Standard Specimen
5	3-22 5		422		4·485		
	3-23-38	1 33	972	450	3·985	9·00	Whitworth's Hard Cast Iron
6	3-37-35		800		4·485		
	3-39-15	1 20	1,196	396	3·985	7·92	Standard Specimen
7	9-37-40		921		3·970		
	9-38-27	0 47	1,133	212	3·470	4·24	Standard Specimen
8	9-42-43		430		3·970		
	9-43-30	0 47	640	210	3·470	4·20	Standard Specimen
9	9-51-55		172		3·970		
	9-53-8	1 13	525	353	3·470	7·06	Whitworth's Soft Steel
10	9-58-30		5		3·970		
	9-59-45	1 15	358	353	3·470	7·06	Whitworth's Medium Steel
11	10-6-30		918		3·970		
	10-7-15	0 45	1,128	210	3·470	4·20	Standard Specimen
12	10-17-44		653		3·970		
	10-19-6	1 22	1,055	402	3·470	8·04	Whitworth's Hard Steel
13	10-20-45		595		3·970		
	10-22-12	1 27	1,039	444	3·470	8·88	Whitworth's Hard Steel
14	10-32-35		710		3·970		
	10-33-23	0 48	945	235	3·470	4·70	Standard Specimen

* *i.e.*—Number of revolutions of drill per $\frac{1}{100}$ in. of depth.

TABLE XXIV.—ELASTIC CONSTANTS AND ULTIMATE

TENSION.

1 MATERIAL	2 No. of Bar	3 Diameter of Bar	4 Area of Bar	5 Modulus of Elasticity	6 Elastic Limit	7 Yield Point	8 Maximum stress
		Inches	Sq. ins.	Lbs. per square inch.	Tons per sq. in.	Tons per sq. in.	Tons per sq. in.
Soft Steel	1	0·623	0·305	29,990.000	6·56	11·47	26·60
Do.	2	0·623	0·305	29,860.000	8·20	13·93	25·93
Do.	3	0·623	0·305	29,990,000	7·38	13·11	26·33
Medium Steel	7	0·622	0·304	30.330,000	6·58	9·87	28·75
Do.	8	0·622	0·304	30,330,000	6·58	9·87	28·91
Do.	9	0·623	0·305	30,000,000	6·56	9·83	28·99
Hard Steel.....	13	0·622	0·304	30.385,000	13·16	19·74	46·83
Do.	14	0·623	0·305	30,100,000	13·11	19·67	46·83
Do.	15	0·621	0·303	30,233,000	13·25	19·80	46·49
Soft Cast Iron ..	19	0·621	0·303	8,460.000	..	..	6·01
Do.	20	0·619	0·301	8,620.000	..		5·52
Do.	21	0·620	0·302	8,134,000	..		5·51
Medium Cast iron..	25	0·618	0·300	14,300,000	..	..	11·46
Do. ..	26	0·621	0·303	14,300.000			11·45
Do. ..	27	0·621	0·303	14,500,000	..	..	10·85
Hard Cast Iron....	31	0·621	0·303	14,850,000	..	..	7·61
Do.	32	0·621	0·303	14,810,000	..	..	7·32
Do.	33	0·623	0·305	14.500,000	..	..	9·02

STRENGTHS OF MATERIALS OPERATED UPON.

			COMPRESSION.					
9	10	11	12	13	14	15	16	17
Per cent. Extension on 4in.	Per cent. Reduction in area	No. of Bar	Diameter of Bar	Area of Bar	Length of Bar	Modulus of Elasticity	Stress per square inch	
							Elastic Limit	Yield Point
28·8	54·8	4	1·247	1·221	2·50	29,790,000	6·55	11·46
21·2	37·1	5	1·247	1·221	2·50	30,180,000	5·73	12·27
24·5	44·3	6	1·247	1·221	2·50	30,580,000	6·14	11·40
26·5	37·5	10	1·247	1·221	2·50	29,660,000	4·91	10·24
25·4	36·5	11	1·247	1·221	2·50	30,175,000	4·91	10·24
25·0	37·7	12	1·247	1·221	2·50	30,175,000	4·91	9·82
13·5	20·0	16	1·140	1·021	2·50	30,860,000	9·79	20·57
14·5	18·0	17	1·141	1·023	2·50	30,750,000	9·78	20·53
11·5	10·5	18	1·140	1·021	2·50	30,610,000	9·79	20·57
Breaking load on bars 1in. by 2in. deep on 3ft. span.							Crushing Stress Tons per sq. inch	
Cwt.		22	1·247	1·221	2·50	8,500,000	28·61	
25		23	1·248	1·223	2·50	8,170,000	25·76	
		24	1·247	1·221	2·50	9,040,000	26·38	
		28	1·248	1·223	2·50	13,700,000	43·90	
31 to 32		29	1·247	1·221	2·50	14,150,000	44·00	
		30	1·247	1·221	2·50	14,070,000	44·00	
		34	1·244	1·215	1·250	14,670,000	39·67	
35		35	1·248	1·223	1·250	14,350,000	45·07	
		36	1·247	1·221	1·250	14,600,000	45·71	

TOOL-STEEL EXPERIMENTS.

VOTES OF THANKS AND REPLIES.

On the conclusion of the reading of the report the PRESIDENT (Mr. E. G. Constantine) said it was not proposed to discuss it that evening. Possibly there were gentlemen present who had been able to grasp the full significance of it, but he had no doubt the majority would agree with him, that there was a great deal in the paper which ordinary minds would require some little time to think over, before discussing same.

He had now to perform a duty, which was always a pleasure to him, to recognize the assistance they had received, and he would ask the members first of all to accept a proposition from himself:—

> "That the best thanks of the Association be tendered to Dr. Nicolson for the part he has taken in carrying out the Tool Steel Experiments."

Dr. Nicolson, as reader of that report, had had the most of the work to do in connection with these experiments, and as they would see from the report, a very large amount of industry had been necessary in its preparation. In addition to this, he ventured to think that the report, as it stood, would constitute a monument to the School of Technology, as to what could be done in the way of research, and also to the very high scientific attainments possessed by Dr. Nicolson. He need not dilate upon Dr. Nicolson's attainments, they spoke for themselves, and if they had not known of them before, the experience of this report would have convinced them in that direction. He would ask Mr. Henry Webb to second the resolution.

Mr. HENRY WEBB, in seconding the resolution, said it was somewhat difficult to find words at a moment's notice like that, to adequately express their sense of indebtedness to Dr. Nicolson, and all those who had helped in the elaborate series of trials just presented. He quite agreed with the President, that from the reading of the paper, an ordinary man could not grasp everything concerning it, but he thought that any ordinary man could grasp the fact that there had been a very great task, and most patient, careful and thoughtful work, and for that reason he thought they were indebted to the head of the concern Dr. J. T. Nicolson. As the President had also stated in moving the vote of thanks, they ought to be proud in Manchester and District (for they in Bury had a little share in Manchester), that there was a School of Technology that had the facilities, and the staff, to undertake such a marvellous series of trials. He did not think there was any other place in which those tests could have been made and carried out so successfully as they had been done in the Municipal School of Technology, and he thought it would surprise the engineering world when those tests were published; and they could be quite sure that eventually those tool steel tests would be flashed all over the world. Their American friends were often asking "when are you Britishers going to finish those tool steel tests of yours," and he now thought their American friends would be the first to acknowledge that these tests were a very large contribution to the science of metallurgy, especially the Metallurgy of Steel. He could assure Dr. Nicolson that every member of that Association valued most highly his services, and appreciated them very much; and they would go home and read that report most carefully and thoughtfully, and, if they were spared until November 7th, he hoped they would have a very good discussion.

He very heartily seconded the vote of thanks to Dr. Nicolson.

Mr. A. Saxon said he rose to congratulate Dr. Nicolson and the Committee on the excellent result of their experiments, and he had to thank Dr. Nicolson, personally, for carrying out a small experiment on his (Mr. Saxon's) behalf. He called upon Dr. Nicolson a few days after the last meeting, and asked if he would undertake a test for him with two tools placed side by side, each taking a $\frac{3}{16}$in. depth of cut, as against one tool taking a $\frac{3}{8}$in. cut. That experiment was made on Friday last the 6th inst., by Dr. Nicolson's assistants who recorded the results. The single tool of $1\frac{1}{4}$in. square steel working on cast-iron with $\frac{3}{8}$ths depth of cut by $\frac{1}{8}$th traverse, lasted 15 minutes, and the two tools working under similar conditions as to total depth of cut, speed, and traverse, lasted 52 minutes; and but for a slight slip owing to the tools being rather short, which prevented them being quite firmly secured by the tool holders would probably have lasted 60 minutes; this would indicate that with two separate cutting edges, and the extra amount of material in two tools over one in absorbing the heat produced by the cutting, gave increased powers of resistance to the tools.

When they looked at the tables and saw the results of high speed cutting with similar depth of cuts, they would see that the chances were greatly in favour of the two tools coming out as expected. He did not know how that compared with Dr. Nicolson's particulars of the test, he simply knew the time one tool lasted, and the time the two tools lasted under similar conditions.

There was not the slightest doubt this question was most important to all engineers, To some of them, it was perhaps not of so much importance as to others, as many bought steel forgings "rough-turned," so that there was not that amount of rough turning of steel and wrought-iron as one would expect in engineers' own shops, but it was interesting to know that in even a small works like their own, during the last 12 months

they had removed in Cast-Iron turnings and borings 108 tons 7 cwts.; Steel and wrought-iron, 77 tons 14 cwt.; Brass, 4 tons 14 cwts.; making a total of cast-iron, steel, wrought-iron and brass for the year, 185 tons, 15 cwts. With his firm, therefore, it was important, and there were other firms with a much larger output to whom it meant considerably more.

But these tests ought not to mislead firms who have heavier work in iron and steel to be machined. The Committee had no doubt selected 1½in. size of steel by way of being a very handy size, easily handled at the School, but in large works where there was a great amount of heavy cutting to be done, it might be found that a larger section of steel would be better and give better results. For the experiments the size adopted was a very handy one. He had made a brief experiment of his own that day, and had brought down the patterns of the tools to the meeting (produced). There was one tool ground in the ordinary way suitable for giving one ⅛in. cut on cast-iron, and a similar tool altered into a double cutting tool each cutting edge taking a cut of $\frac{3}{16}$in. deep. The double tool did more work and lasted longer than the single tool when taking the same total depth of cut at the same traverse and the same cutting speed as the tool with the one cutting edge.

The PRESIDENT said, "Dr. Nicolson, I have very great pleasure in presenting you with the hearty vote of thanks of the Association for your valuable services in this connection."

Dr. NICOLSON, in reply, said he thanked them most deeply for the very kind and far too flattering way in which they had referred to him. He was not going to make a lengthy speech, but would merely like to say that this work had been a very great pleasure to him, and he was only sorry that, so far as the Committee were concerned, it had almost come to an end.

Notwithstanding the considerable amount of work which was represented by the results of the report, they really knew very little about the matter. They were only now beginning to know in what direction to work in order to find out something about the subject; and if it were possible for them, in that School, to have the lathe that Messrs. Armstrong, Whitworth had loaned, for a further considerable length of time, as also the rest of their material which had not been used up, and if the School Committee would agree to bear the cost of the power which would be required, he thought that a very great deal more might be learned about the working of these steels.

For instance, they knew absolutely nothing about the way in which the durability of the steel depended on the cutting angles, or the shape of the tool. They had discovered no law connecting the wear of the tool with its cutting angle. Some tools, for example, which were very sharp and for which the cutting force was small failed as soon or sooner than other tools did with a blunter angle and a greater cutting force. They also knew very little about the way in which the cutting force depended on the angle. Such intricate questions as that of the effect of the shape of the tool upon the conduction of heat along it and its emission from the surface had not been gone into at all.

He would like to say further that although it was very well for the members to pass a vote of thanks to him for writing the report, yet the value of that report was largely due to the sound common sense of the Committee who had kept the scope of the research within the bounds of working usefulness.

He had in the course of this work learned to know some of the Members of the Committee very well, and these he hoped to encounter in future as his friends. Their sound engineering instinct has been of very great advantage in the carrying out of the research.

He thanked the members for their vote of thanks.

The PRESIDENT said:—They had now to express their indebtedness to the firms of tool steel makers who had participated in these experiments, and without whose co-operation the work would have been impossible. He therefore proposed—

"That the best thanks of the Association be conveyed to the undermentioned Firms for their co-operation with the Joint Committee in respect to the tool steel experiments recently carried out at the School of Technology, especially in supplying tools for experimentation, and in courteously arranging for representatives to attend the tests."

FIRMS; Messrs. Sir W. G. Armstrong, Whitworth & Co., Ltd.
,, John Brown & Co., Ltd., Sheffield.
,, Samuel Buckley, Birmingham.
,, Charles Cammell & Co., Ltd., Sheffield.
,, Thos. Firth & Son, Ltd., Sheffield.
,, Samuel Osborn & Co., Sheffield.
,, Seebohm & Diechstahl, Ltd., Sheffield.
,, Vickers, Sons, & Maxim, Ltd., Sheffield.

And in coupling those names with the resolution, he would like to add how much they were indebted to the representatives of those firms, who themselves had attended the tests. He was in just the same position as Dr. Nicolson in this matter, and probably the other members of the sub-Committee felt the same, that they had extended their knowledge considerably of tool steel through the information gained from the representatives who attended the tests on behalf of the firms of tool steel makers, and he would ask the members to record their appreciation of the services rendered by these firms. This resolution would be forwarded to the firms concerned, but if there were any of the representatives present who would like to make a few remarks, they would be very glad to hear them.

Mr. TIMOTHY SHAWCROSS said, in reply to the vote of thanks kindly given to the tool steel representatives on

behalf of the tests carried out at the Municipal School of Technology for Messrs. Armstrong, Whitworth & Co., he could assure the members that the tests had been carried out in a most perfect manner. The committee and assistants of the School rendered every assistance in their power, especially during the earlier stages, when various difficult points presented themselves. Great credit was due to Dr. Nicolson and the committee for the splendid results. The assistance these gentlemen had given to the tool steel representatives was quite equal to any the representatives had rendered.

The PRESIDENT said, he had now to ask the members to record their appreciation of the generosity of Messrs. John Hetherington & Sons Ltd. in the first instance, and of Messrs. Armstrong, Whitworth & Co. later.

Messrs. Hetherington lent a lathe to the Committee, which unfortunately was not large enough for the work that was required to be done, but some useful preliminary work had been carried out on this lathe, which enabled them to judge as to what was required subsequently.

Messrs. Armstrong, Whitworth & Co. had been particularly good in this matter. In addition to participating in the tests by furnishing tools, they were good enough to lend to the Joint Committee, a lathe which was of sufficient capacity to carry out the work required, and in addition to that, they most generously gave, free of charge, all the material which was operated upon, thereby saving the Association a very considerable sum of money; he did not think an action like that ought to pass without the members recording their very hearty appreciation of the services rendered by the firms mentioned.

To Mr. Gledhill, on behalf of Messrs. Armstrong, Whitworth & Co. he had pleasure in presenting this resolution, and

also to Mr. Hetherington (who was also present) on behalf of Messrs. Hetherington.

Mr. J. M. GLEDHILL (Armstrong, Whitworth & Co.) thanked the members on behalf of his firm for their kindness in acknowledging the loan of the lathe, and the material that the firm had made. When his firm were first approached on this subject, they thought it of such importance, that they did not hesitate one moment, but did all they could to put into the Committee's hands suitable means for making these experiments. He felt they must all agree, that the most excellent paper which Dr. Nicolson had compiled, was quite unprecedented in its line, and the information he had given to them on the subject of tool steel, must be of equal value both to users of tool steel as well as to the makers. As the discussion on this subject would come on later, he would defer any remarks he had to make on the various points of the paper.

With regard to the further loan of the lathe, he felt his firm would do that with very great pleasure, and should any further material be required, he thought they might be able to find some, as they had still a little scrap left at their works. He must however make this "rider" with regard to the lathe, namely: that Dr. Nicolson, when he had finished with it, would send it back, and not try to bring on to his firm the "statute of limitation."

He thanked them all very kindly, and wished to repeat how interesting this report had been.

Mr. E. P. Hetherington, on behalf of his firm, thanked the members very much for the resolution which had been passed.

The PRESIDENT: They now came to the votes of thanks to the Manchester Corporation, and the various authorities connected with it. As the members would notice in the introductory

portion of the Report, Sir James Hoy (then Mr. Alderman Hoy) and Mr. Reynolds, when they were approached upon this subject of tool steel experiments, on the suggestion of their valued member, Mr. Webb, fell in with the idea very readily, with the result of which they knew, and he (the President) therefore begged to move—

> "That the best thanks of this Association be conveyed to the Manchester Corporation, and to the Technical Instruction Committee."

And he coupled with it the names of Sir James Hoy, Mr. J. H. Reynolds (the Principal), and the Chairman of the Joint Committee, Mr. Nasmith, whom he was very glad to see present, and his successor, Mr. Hiller. They had invariably experienced the greatest courtesy and willing assistance on the part of the Manchester Corporation, and the sub-Committee of the Technical Instruction Committee, and their co-operation had been such that he (the President) could only express the desire that if ever it was his lot to be again engaged in similar work, he might be associated with the same gentlemen. He would therefore ask the members to pass this resolution, coupling with it those names, and also the name of Mr. Robson (the vice-Principal), who had been of great assistance, and his successor, who had recently come upon the scene, Mr. Wrapson. Mr. Reynolds, unfortunately, was unable to be present that evening, but they had Mr. Nasmith and Mr. Hiller present, to whom he would convey this resolution, and would be glad to have a few remarks from those gentlemen.

Mr. Joseph Nasmith said: He hardly knew how to regard himself that evening, as, though he happened, at the time these tests were initiated, to be Chairman of the Engineering sub-Committee of the school, unfortunately before the tests were completed he had to drop that position which was handed over to much

more capable hands, those of Mr. Hiller. He could only say, that at the time these tests were suggested the Technical Instruction Committee, although very desirous of doing everything possible, was spending a good deal of money, and required to be convinced that the tests were likely to be of real value, and show, when they were published, that the school was really capable of doing some very useful work. He was certain, when that report went out, and got noised abroad through the whole of the engineering world, the Technical Instruction Committee, and the Committee in general, would feel that they had accomplished a valuable task, which however had not been done without a considerable amount of labour. As far as he personally was concerned, the amount of labour he had been able to give had not been anything like so great as that of some of the other members of the Committee, and whatever misgivings there were at the outset, as to their getting adequate value for the cost which these experiments entailed, he did not think that anybody, after having read the elaborate report by Dr. Nicolson, could form any other opinion than that they would be of the greatest value to the whole of the engineering world of this country. If he dared comment upon what they had done at that school, and what had been done in America—that "Land of Promise" which led the way in everything connected with engineering, and metallurgy—although England had always been supposed to be years and years behind the times—he would like to compare these tests with a series of tests which were made and reported on in the Journal of the "Franklin Institute." The latter were practically confined to two or three tool steels, which were, more or less, the property of the firms making the tests. Now, at any rate, the present tests had been made without fear or favour, with a number of tool steels kindly supplied by different makers. Their elaboration, and the deductions which had been drawn from them, were, in his judgment, very much superior and of

greater value than any similar work which had been done on either side of the Atlantic. He thought they, in Manchester, might claim to have "scored one" from their brethren on the "other side," especially in the impartiality shown, which followed upon the lack of pecuniary interest in any particular brand by any of the members of the Committee, a condition which did not always prevail. For the Committee, and the Committee of the School, they would feel, now that this work had drawn to a close, that they had been most usefully engaged, and had done a great deal of service to the whole engineering industry of this country. They would also feel that the Report, which by and by would be a published production, was a worthy test of the useful capacity of a great school like that, and was a distinct credit to the members of the Association with whom the idea originated.

Mr. E. G. Hiller said he really thought Mr. Nasmith had replied so adequately for the Corporation, that it was not necessary for him to say anything further. He had attended that evening as a member of the Association, in the private capacity of a member. Like Mr. Nasmith, however, he would like to say that as a member of the Technical Instruction Committee, although he had only been a short time on that Committee, one of the most interesting questions he had come in contact with had been this series of tool steel experiments.

With regard to the Committee of the School of Technology, he might say with reference to these experiments, that they looked at them broadly, and were always willing to consider anything that was to the interests of the great engineering profession of that district. The school had, of course, for its object, the education and training of young men as engineers, but an important branch of that work was in the direction of research, and he, himself, hoped and anticipated that the

series of experiments which had been reported to them that evening, was only the first of a number which would be of benefit and interest to the engineering trade of the district.

The PRESIDENT remarked, as the members would gather from the report, the staff of the School of Technology had been very freely drawn upon, and he would now ask them to show their appreciation of the services rendered by:—

Mr. Dempster Smith, who had had a great deal to do in the tabulation of the results.

Mr. Anderson, his predecessor.

Mr. A. Adamson (Lecturer in Physics), for making the physical tests of the materials.

Mr. E. L. Rhead (Lecturer in Metallurgy), for making the chemical analysis.

Mr. W. C. Popplewell, M.Sc. (Lecturer in Mechanical Engineering), for making the mechanical tests.

And in addition, to these gentlemen:—

Mr. J. T. Hodgson, Mechanical Superintendent of the School, to whom they were very greatly indebted for his practical knowledge, and Mr. C. Coupes, the Turner.

The PRESIDENT could only say, with regard to Mr. Coupes, that if ever he required a good turner, that was the man he would like to get hold of. He would now ask the members to pass their vote of thanks to the gentlemen named.

Several of these gentlemen were present, and they would be very glad to hear them if they wished to speak. He saw Mr. Rhead there—an old friend, and would like to hear his voice.

Mr. E. L. RHEAD said that: The little he had been able to do in connection with those tests had been a very great pleasure, and he had been deeply interested in the results. Those results had taught him very much concerning the working properties

of certain types of tool steel. He had no doubt but that the report would become a classic that would be quoted from frequently.

The PRESIDENT said: They now came a little nearer home, and he wished the members to pass a very hearty vote of thanks to the Sub-Committee of the Association, who had had those tests in hand, and in connection with the resolution he would like to couple the names of Mr. H. N. Bickerton, Mr. George Daniels, and Mr. Daniel Adamson.

He was quite sure that both Mr. Bickerton and Mr. Daniels would agree with him, that a special measure of thanks was due to Mr. Adamson. There was no doubt about it. Mr. Adamson had displayed in this matter a very great amount of perseverance and practical knowledge, which had been a great factor in bringing those tests to a conclusion in the time they had to do them. Had it not been for Mr. Adamson, he ventured to think that none of them would have been kept up to the mark as they had been. (Applause.) He asked those gentlemen to accept the best thanks of the Association.

Mr. DANIEL ADAMSON, in reply, said: The President had omitted to mention that he (the President) had done quite as much as any other member of the Committee.

With regard to himself (Mr. Adamson) he had been chosen as Honorary Secretary, and he was told that his business was to make other people work. The members had heard that he had done so, but credit was due to each member of the Committee equally for what had been done.

He did not know whether he would be in order, but there was one gentleman who should be thanked for having really started this investigation, and if he were present he would have told him that he then ran away and left them—that was Mr. Charles

Day. The scheme originated with Mr. Day, and their thanks were therefore due to Mr. Day for making this most valuable suggestion.

With regard to himself (Mr. Adamson), as he had to speak for the other members of the Sub-Committee, he thanked them very much for their vote of thanks.

The PRESIDENT, in closing said: They did not propose to have any discussion on the paper that evening, but as there were several gentlemen present who had come from a distance, and who might find it inconvenient to be present on November 7th, if those gentlemen had any remarks to make the members would be glad to hear them. If there were no gentlemen desirous of speaking, they would now have an opportunity of inspecting the tools at the close of the meeting if they desired to do so, and he hoped that a fortnight hence they would have at the meeting to be held in this same room of the School of Technology as good an attendance as they had to-night. He was quite sure that however valuable that report was its usefulness would be greatly increased if they would attend the discussion and give their own experience of high-speed cutting tools which would be of great interest to all.

DISCUSSION

AT THE

MUNICIPAL SCHOOL OF TECHNOLOGY,

SATURDAY, 7TH NOVEMBER, 1903,

PRESIDENT, MR. E. G. CONSTANTINE in the Chair.

The PRESIDENT in opening the meeting said: The evening, as the members knew, was to be devoted to discussion on Dr. J. T. Nicolson's Report on "Tool Steel Experiments," but before commencing, he would ask Dr. Nicolson to make a few supplementary remarks. A number of visitors were present, and they were quite expecting Mr. Wicksteed, the President of the Institution of Mechanical Engineers, whose firm had been carrying out experiments in a similar direction, and if he had been present he would have been able to give them some valuable information. Unfortunately, however, the fog had prevented his being present, and he had sent a telegram to that effect. The Society would be very pleased to hear the remarks of any visitors present if they wished to speak on the subject, and he would further ask that all speakers confine themselves as closely as possible to the main points of the subject, which was a very large one. Dr. Nicolson would make a few supplementary remarks.

Dr. NICOLSON then described certain additional results and a new diagram which had been prepared since the last meeting of

the Association, and which gave the relation between the cutting stress and the elastic properties of the materials operated upon. [These remarks and that diagram having since been incorporated in the report, it is unnecessary to repeat here what was said].

Mr. E. P. Hetherington said: Like a previous speaker, he thought the Association was indebted very greatly to the originator of these tests. Also to the Committee and Dr. Nicolson, for the very great amount of time they had devoted to the work. He found that the time given to each firm's tool tests occupied, when the tools did not fail, 710 minutes over the whole 24 tests, and standing over the lathe, the Committee had spent 83 hours actual testing. If they would multiply that by 10 times, the Committee had spent about 800 hours over these experiments. In part of the report it was stated that the Committee had not been at any pains to specify which in their opinion was the best tool steel, but left it to the users themselves to get at this result. With that idea in view, he had prepared a short table, putting the results from a purchaser's point of view—all on one sheet, He found that out of 24 tests of Armstrong's steel, they failed with two tools.

Out of 24 tests by	Buckleys	10	tools had failed.
,,	Browns	12	,,
,,	Cammell	9	,,
,,	Firth	9	,,
,,	Osborn	9	,,
,,	Seebohm & Dieckstahl.	10	,,

That proved to his mind that Armstrong's steel was the best, in that it caused workmen to leave the lathe to go to the grindstone fewer times than any of the others. Armstrong's were allowed, as with all the other firms, 710 minutes during the tests. Out of this period of 710 minutes,

they (Armstrong, Whitworth)...lost 27 minutes.
Buckley ..... „ 134 „
Brown ..... „ 218 „
Cammell ..... „ 140 „
Firth ..... „ 100 „
Osborn ..... „ 192 „
Seebohm & Dieckstahl..... „ 135 „

The total amount of weight removed :—

By Armstrong, Whitworth.....was 1,827 lbs.
Buckley ..... „ 1,458 „
Brown ..... „ 1,299 „
Cammell ..... „ 1,445 „
Firth ..... „ 1,722 „
Osborn..... „ 1,439 „
Seebohm & Dieckstahl ..... „ 1,485 „

He (Mr. Hetherington) found further, that for the whole period of time taken by each tool maker, that although Armstrong's might appear to be first in the list, the weight removep per minute, at the disposal of each tool maker, was :—

Firth ....removed 2·82 lbs. per minute.
Osborn..... „ 2·77 „
Armstrong, Whitworth ... „ 2·66 „
Brown ..... „ 2·64 „
Seebohm & Dieckstahl..... „ 2·60 „
Cammell ..... „ 2·37 „
Buckley ..... „ 2·33 „

Of course, that did not take into account the time lost ; but that was the time each had been working, and it was strange, that even under those conditions, the results were so regular. He was rather disappointed, taking the tests all through, considering heavy cuts and light cuts, that there was only an average slightly over 2½ lbs. removed per minute, which seemed

very light for the whole period of the tests. There was not much more than half a pound per min. between the highest and the lowest. In the experiment No. 26, Table VIA., the cut, which is given in Report, page 245, as $\frac{3}{8}$in. × $\frac{3}{8}$in , was actually a little over a $\frac{1}{4}$in. × $\frac{3}{8}$in. The time allowed for that test—viz., 5$\frac{1}{2}$ minutes—was very short indeed. Why so short a trial? The report did not say which firm's steel was used in this test (the cutting speed was 25·4, and nett HP 23·4).

He would like to know, with the permission of the President, what class of "finish" these high-speed steels gave, and if the finish on the steel shaft was such as would pass inspection.

Referring to Tables XX. and XXI., he noticed that all the tools had failed on cast-iron, and in the top portion of the table very few of them (four only) had gone the two hours without failure, but the weight removed, average 3$\frac{1}{2}$ lbs., was a little in excess of what he had before stated, while the lower table (XXI.), the medium cast-iron, was much below—viz., 1$\frac{1}{4}$ lbs. It seemed to be very low indeed. His opinion was that the tests were most interesting, but still rather disappointing in the weight of material removed, and he was of the opinion that the tool-maker with modern machine tools was much ahead of the steel maker.

Mr. CHARLES DAY said: Before speaking about any of the purely technical questions which arose in great number out of the report, he would like to say a word or two in reference to a serious difficulty which for some time seemed to wreck the prospects of these tests being carried out. The difficulty was that when the matter was brought before the City Council, the members of that Council, also several members of the Technical Instruction Committee expressed the opinion that when these tests were made, the result would be to show that some particular firm's make of tool steel would give results better than others,

and that the report would be used largely for advertising purposes.

They could easily see that this was a very serious difficulty indeed, because the City Council could hardly sanction the expenditure of public money if such a result were likely to take place. Very many arguments were used to combat that idea and show that the probabilities were otherwise. It was therefore a matter of some considerable gratification, and he must also confess, of some relief to himself to find that those arguments had been fully justified, in-as-much as, speaking for himself, he was unable to trace that any one firm's steel was better than all the others. There were several makers of steel which showed about equally good results.

He thought that was something they ought to be thankful for, because it meant that the report instead of being used in the narrow sphere of a trade advertisement, would be looked upon from a much broader view, and analysed for the information it gives about steel cutting. The object he had when he urged this matter was that these tests should be carried out by an independent authority of some kind, and so try to establish a standard of reference for their shops. He felt that before anything new could be effectively used in any branch of trade, they, who had the control of works must themselves first know what was possible of achievement, and he thought the report showed what was possible, and placed a very good standard before them which they ought to set to and try to reach. That it did constitute a valuable standard of reference and information he was convinced by trial. Immediately he had received a copy of the report, about 10 days ago, that same day he had copies made of Plates III. and IV. showing the speeds possible with different materials, and had a copy transmitted to every foreman and charge-hand at their works (The Mirrlees Watson Co., Glasgow).

He was pleased to say that the 10 days run on those lines had made more improvement in their shops than had ever taken place in any three months before. The foremen, without a single exception, said that these curves and particulars were of the greatest possible help to them in their work. As some guide to the manner in which he had tried all the curves mentioned, he started with the assumption that the average forgings in their works would correspond to the medium steel forgings used in the test. He might have been taking too easy or too hard a condition. However he had taken that condition, and was pleased to say they had been able to get almost the results shown on that curve, and as far as their results indicated, that curve was quite good practice if they attained to it. With regard to cast iron, he assumed that their castings would correspond to the medium castings of the test. They could about follow those figures, except when cutting the skin, when they had to reduce the speed.

A point in the report had interested him, and it was a point he thought most of the members present must feel somewhat dubious about, viz:—that part which stated that when the speed of cut was increased, the force or stress on the tool was not increased, but rather reduced. His personal experience showed otherwise, or at least it indicated otherwise. It did not prove, but certainly indicated this, as in turning a part like a piston rod at such a speed as would give a satisfactory finish, that was to say at a speed which gave no undue spring or chatter, if they increased the speed, though still cutting below the possibilities of the steel, they got chatter, and the finished work was not then satisfactory, indicating that greater stress was brought to bear with very light cuts when the speed was increased, although the cut itself had not been increased. He thought it would be of great interest if the various members of the Association would state their experience in that direction.

Another point that arose out of the tests was this, they had heavy cuts, moderate cuts, and comparatively light cuts, but it had not been possible to test anything about scraping or finishing cuts. It gave one far from a pleasurable feeling, going round a shop, to see a job that was having a scraping finishing cut running at a slow speed to give a nice surface. So far his experience was that they could not finish work at high speeds. If anyone could get over that difficulty they would add another step forward. The question of increased stress and increased speed was also of great importance, because, if cutting at a high speed did not increase the force or stress on their existing lathes they could increase their output by speeding up. If on the other hand there was increased stress as the speed rises, they could not do that nearly so well. The point was therefore of distinct importance, as affecting the continued use of their existing plant.

Another point he had met with, which had arisen out of the use of these steels, was that a great deal of output was lost in consequence of coarse speed variation, when the belt was moved from one cone to another. The range of speed between one cone-step and the next was too great in most lathes, with the result that he often found, on looking at a job, that it was cutting at a speed which certainly was not by any means the highest possible, yet it was not possible to take the belt on to the next cone, as the speed would then be too high or too near the critical speed. To get over that, on their 8ft. boring and turning mill, he tried driving this through the medium of Reeves' Variable Speed Gear, which gives variation of speed throughout its limits, and its limits corresponded to about three steps on the cone. As a consequence, in that way, they could always, without fail, get the speed of the lathe to the exact point desired. The nett result had been a very decided increase in output from that particular machine. There were numerous points which could be found

out from these tests, but he preferred that most of them be raised by other sources.

He would like to ask one question from their metallurgical friends about the tensile tests, which puzzled him. In the medium steel, the tensile strength of the steel was higher than the tensile strength of the soft steel. Strange to say, their yield point, or "limit of elasticity," was lower instead of higher; further, the modulus of elasticity for hard, medium, and soft steel was practically uniform, and that seemed to him an interesting point which required some explanation, because, really if the "yield point" of the medium steel was lower than that of soft steel, they ought to use soft steel a great deal more than they did.

In conclusion, he would like to remind some of the members who may not have seen the comment in last week's issue of "Engineer"—where, in a leading article, the "Engineer" stated that "on no occasion had any Technical College ever lent its aid to such an important series of tests as these."

Mr. Henry Webb said he was sorry the President had called upon him to speak for the second time, but he might say he had been reading a book during the last week—sometimes he did read a book. The book was entitled, "A Merchant's Advice to his Son." One sentence struck him as being a very good one. In one of the letters, the merchant tells the son, "if he had anything to say, say it, and sit down. It was much easier to look wise than talk wisdom." (Laughter.) When he entered that room, he fully intended carrying out that advice to the letter—to sit still, and look wise, so that he would not have to "talk wisdom." He took it for granted they were all very grateful to Dr. Nicolson and his staff for the wonderful work they had undertaken. It was utterly impossible to really discuss that report, because it was a statement of facts, and they could

not dispute those facts. They might discuss matters which arose from them. He hoped the Committee, and some of the staff, would tell the members of some of the other problems that arose. They were the most valuable things in the paper, and required very careful consideration.

As regards the paper itself, two questions occurred to him, and he had learnt one or two lessons from it. One question was, what would have been the effect on the tool in removing the skin? In their works they had to remove the skin first of all. The one tool had to do the whole lot; they could not put another tool in. As a matter of fact, no tool could go ahead until this skin was first removed. He would like to know what was the effect upon the tool steel when removing the skin.

He would also like to know, and would be very glad if any member present could tell them, something about the cutting angles of tools. It was not clear to him what inference they wished members to draw from those cutting angles. He always thought one cutting angle was a great deal better than another. He had several men with whom he came into daily contact, who would say, "I can grind a tool better than anyone in this shop." He had learnt from the report, first, this lesson, as Mr. Day had stated, that they must have it as a standard of reference, and their workmen must work up to that standard. The men will have to be told the thing could be done, and that is what they have to come up to. They must also try to educate their men that heavy cuts are better than light cuts, and do not take the power they imagine. The second lesson he had learnt was quite in opposition to Mr. Hetherington. He (Mr. Webb) thought the tool maker was a long way behind, and now he had a grand opportunity. The tool makers should go round to their shops, and say, "Scrap those old tools of yours, and buy our lathe, &c., specially designed for the use of high-speed cutting steel." He thought if he was a tool maker, he could make a lot

of money just now. Tool makers would have to take advantage of these high-speed tools, in the light of the recent tests, and now was the time.

The steel makers had also something to learn. He would not be surprised to find men who would say, "My father used to make cutting tools out of an old mule spindle, which has done quite as good work as any of these new tool steels," or, "My father many times used a chilled cast-iron tool." The steel makers had something to learn, and he was glad Mr. Day had pointed out the moral, that these tests were not to show the best steel maker. They were all good, but he thought they would learn this, that there were two kinds of steel required for commercial work—one for steel forgings, and a very different kind of steel for cast-iron.

Another point. One or two of his customers, very smart men, asked if they were using the high-speed cutting steel at their works. On being answered in the affirmative, they immediately ask, "Why don't you reduce the price, you are rough-turning so much quicker than you used to do?" They had a ready answer that they already foresaw all this, and therefore had reduced the price to below cost, and therefore could not do it at any less.

Mr. W. H. Cook said: On careful consideration of the paper which they were met to discuss to-night, two things stood out very prominently:—

1st.—The amount of trouble and care which had been expended in its preparation, and the really excellent manner in which the results had been arranged and tabulated.

2nd.—The comparatively small amount of additional practical information which had been given to them over what the old mechanics told them in their apprenticeship days. Run slow and cut deep was their motto, and this seemed to be what the paper suggested if they desired to remove the most material.

There were so many points which had been left untouched that he sincerely hoped the experiments would be continued, and if it was a question of finance, he trusted the Society would rise to the occasion and enable them to take advantage of Dr. Nicolson's great knowledge to carry the experiments to a successful conclusion.

There was one thing the results had helped them in, and that was to decide which steel would best suit their purpose without having to spend the time and trouble necessary in a workshop.

The part of the paper which appealed to him most was that dealing with cast-iron. There were one or two points in relation thereto on which he should be pleased to have some further information.

How has the standard of hardness been determined?

What constitutes hard and what soft cast-iron?

They knew that cast-iron could be made so soft that it could be cut with a knife, or so hard that no tool would touch it, how was this? Was it due to its chemical composition, or to its molecular condition?

Further, they had to deal with castings with the skin on, and he suggested the experiments would have been more complete had some castings been treated in this condition.

Since the paper was read he had had a series of experiments made to see how the new steels would stand when working on ordinary castings.

1st.—When the castings were simply barreled.

2nd.—When they had been pickled to soften the skin.

3rd.—When barreled and annealed.

To do this he had 1,600 rollers like the sample (shown), cast on the same day, and in the same kind of sand, so as to have them as near an equal condition as possible. He had 200 of these barreled in the ordinary way; 500 barreled and pickled, and the remainder barreled and annealed. The steels used were those

in ordinary use in the shop, viz.: ordinary water-hardened, High-Speed Mushet and Whitworth's A.W. The results being as follows:—

Length of roller	$4\frac{3}{8}$in.
Diameter of roller	$1\frac{7}{8}$in.
Depth of cut	$\frac{3}{64}$in.
Cuts per inch...	52.

It will be noticed that the cut was a very shallow one; this arose from the fact that they allowed as little as possible between the casting and finished size to save waste. The fineness of the cut was by reason of the rollers being finished by grinding.

Condition of Casting.	Speeds. Surface.	Traverse.	Number Turned. O	M	W
Barreled	66ft.	2·7in.	4	27	39
Pickled	66ft.	2·7in.	10	88	181
Annealed	66ft.	2·7in.	x	145	450
„	115ft.	4·6in.	x	1	19

From a comparison of these results it would be seen that although the castings had the same chemical constitution the softening of the skin increased the capacity of the tools to a tremendous extent, and also that output may be increased at a trifling cost, the cost of pickling being at the most 3d. per cwt., and of annealing 9d.

In conclusion he would say there was one fault he had to find with the high speed steels, and that was the inability to get from them the same high finish on special work that could be got from the ordinary steel, and he would suggest that the makers try to overcome this.

Mr. D. Adamson asked Mr. Cook what acid he used for pickling.

Mr. W. H. Cook, in reply to Mr. Adamson, said the pickling mixture consists of one part commercial sulphuric acid to 30

parts of water. The castings were put in the mixture at night, and allowed to remain therein twelve hours; they were then taken out and washed by a powerful jet of water. About 25 % of the one part of acid is added daily to allow for wastage of the strength of the mixture.

Annealing was quite as simple, but more expensive; still the results were such as to pay for the expense. The castings were put into iron pots, and packed around with turnings from the same class of castings that were being softened. The pots were put into a suitable furnace and heated to redness, being kept at this heat for about eight hours, they were then allowed to cool off and barreled, when they are ready for use.

Mr. James Vose said: In cutting cast-iron the problem was comparatively a simple one, where they had some cast-iron to cut,—but when they cut sand, wind, and cast-iron consecutively, he thought the problem assumed a different complexion. Mr. Webb had been asking about tools made of cast-iron. It might be interesting to state that he used cast-iron tools in his own practice—several members had seen these tools actually at work—and they were often successful in cases where neither the old nor new steels were equal to the task. The cast-iron tools being of a clumsy character, give more trouble in grinding, which appears their only drawback on certain classes of work.

As some of the steel friends knew, these cast-iron tools were used on a lathe where the speeds were so arranged, that, working at the ordinary rate, it was impossible for a man to cut less than 60 or 70ft. per minute. Then some unsuspecting steel man came along, and advised going up a speed or two, and by going up one speed on the cone it went beyond what any steel on the market would touch. He also found that there were drills made from certain high-speed steels which would act very well if there was a leading hole through first.

Some drills made from the new steels were not too hard, in fact they showed to poor advantage when a soft point attempted to push itself through a hard object. There was trouble with the drilling machine thrust washers and spindle, which almost immediately become overheated. He thought the steels that would not work without first sending a leading hole through were a comparative failure as compared with otherwise inferior steels that would go through the first time. The further they went into this subject, the less ready they were to express any dogmatic opinion on the matter.

There was another point about the new tool steels. The fact of forging being required by some special types of steel rather went against them, in this respect, that the modern idea was to try and produce a tool which could be cut off from the bar and ground to shape without the intervention of a smith, by a man at about 24/- per week. To produce the correct shape of tool and temper it quickly was one point that steel makers would require to aim at.

In machining a job where finish was an object, and the operations on it followed in rapid succession, it often really paid to have a high quality carbon steel in preference to the new steel, and provide very efficient lubrication. This paid better than to keep changing tools in order to try and take advantage of the rapid tooling possible with the high-speed steel. A good price could be given for high-class carbon steel, but it was worth it. He might say that medium qualities of carbon steel now-a-days were not worth while bothering about,—they would perhaps do for crow-bars.

Another point was, that although these modern steels and speeds were to do a great amount of work, meaning less men, the expense would be if anything greater in supervision and management. Where there were men and systems, there must be efficient men to manage them, and therefore it was a point that

required noting, that the class of management for high-speed steel must continue to be of a higher character, and the saving would not be in the supervision, but in the lower range of labour, and the expense of it.

Further, some of the members considered the tools an advance beyond the machine capacity, while others considered the machines well in advance of the tool, but it appeared to him, the modern machine shops were well in advance of the selling and distributing department. It was of no use speeding in one direction if the output could not be disposed of, because it appeared to him that they, as engineers, would have to turn out their products by these steels in quantities, whether there was a demand for them at the moment or not. in order to keep up efficiency. Then, if necessary, they would have to be "dumped" somewhere.

Mr. F. M. Osborn (Samuel Osborn & Co.) said that in the "Times," in reporting Mr. Hadfield's paper before the Iron and Steel Institute, it was stated that "Messrs. Samuel Osborn & Co., of Sheffield, had manufactured muskets of self-hardening steel for many years, and had devoted much attention to the subject." They had not made any muskets of steel, but they were makers of what was familiarly known as "Mushet steel" (the original self-hardening steel) and Mushet High-Speed steel.

In the paper which they were present to discuss, and on which he was allowed to speak as a visitor, the original Mushet steel had been used so largely as a basis of comparison, that he felt it was not out of place to say a few words on the subject.

At the Paris Exhibition, and in the papers relating to the wonderful tests there, comparisons were always made with the original Mushet. He had no doubt some of the members present asked attendants at the Exhibition whether the original Mushet was subject to treatment. The reply of those in charge of the

exhibit had been "Yes; (original) Mushet steel could be improved 40% by the special heat treatment." But he did not think they had put it through their process. His firm had been recommending a simple heat treatment for years. The treatment was as important as the composition of the steel.

As one of those who had taken a deep interest in the Manchester series of tests, he had to acknowledge the consideration with which the steel makers had been received. Nothing, in his opinion, or in the opinion of his firm, could have been fairer than the way the tests had been carried out. He thought the steel makers had learnt quite as much as the tool users. They had learned more from the failures than they had learned from their successes, and he thought great benefit would result. He would point out that with proper heat treatment the results obtainable with the original Mushet steel would be nearer those for high-speed steel. His firm, however, now recommended their Mushet High-Speed steel. Mr. Hetherington had said that he thought the tool maker was in advance of the steel maker. Mr. Webb had contradicted that. He thought everyone would admit that the steel maker had been a splendid friend to the tool maker. The new steels had sold, and would sell hundreds of lathes and drilling machines, and if Mr. Hetherington would accept this amendment, that the steel maker had been a good friend to the tool maker, he thought that would more nearly meet the truth.

With reference to stress, a compression test had been made, and it was shown that Mushet High-Speed steel stood 200 tons per square inch, and hardly moved.

He might say that with regard to the information obtained from these tests, they had recently been quoting for some Mushet High-Speed steel for railway work, and a guarantee had to be given as to what the tools would stand in work. In the tests one of the results was as follows:—With a Mushet

High-Speed tool 1¼in. square, at a speed of 50ft. per minute, reducing the diameter by 1in., with ⅛in. feed, 3021bs. of metal were moved in 30 minutes, or slightly over 101b. per minute. No lubricant was used, and the condition of the tool was quite good. The shaft was steel, resembling the mild steel used in the Technical School trials.

He would like to thank Dr. Nicolson and the Committee for their courtesy to his firm, and the other firms of steel makers, and he thanked the gentlemen for kindly listening to the few remarks he had imperfectly made.

The PRESIDENT said, for Mr. Osborn's information, if he (the President) was right in his construction of the first portion of Mr. Osborn's remarks, he was labouring under a false impression, if he thought there had been any unfair treatment with regard to the endurance trials, and the President would like to put Mr. Osborn right on that point at once. Those endurance trials were made with various steels, not only Mushet, but with ordinary water-hardened, and also high speed and air cooled, and if Mr. Osborn was under the impression that the Committee ought to have referred to his firm before making the test, and given them an opportunity of being present, he (the President) did not agree with Mr. Osborn for a moment. These were not the ordinary tests which were laid before tool steel makers. The tools were treated as ordinarily treated in general engineering works, and they were under no obligation to apply to the makers, either of the Mushet steel, or the makers of ordinary water-hardened steel. He would like Mr. Osborn to be quite satisfied that there was no unfair treatment of his steel, or any other firm's steel.

Mr. OSBORN said he did not wish to convey the impression that they had been treated unfairly, but he took that oppor-

tunity of saying a word on the question of ordinary original Mushet. It was the only steel mentioned by name outside those that had participated in the series of tests. The water hardening steels were made by hundreds of firms, but the ordinary original Mushet was made by his firm only. He thought the opportunity the Society had afforded him of being present that evening was quite sufficient for the purpose he had indicated, but he did not think he was out of place in stating that the original Mushet might be very much improved by a proper heat treatment. He was perfectly satisfied with everything that had been done at the School.

Mr. GEORGE DANIELS said he would like, in the first instance, to refer to Mr. Osborn's statements. He (Mr. Daniels) was one of the individuals who supplied two of the Mushet tools. They were ordinary shaped Mushet tools, and it was very difficult to distinguish them in any other way. They must have a name, so that they knew where they stood with it. Mr. Osborn would agree that when they wanted to make comparisons between the high speed steels, the Mushet, and the ordinary steels, that it was not necessary to go to Osborns for the new treatment, that would not be fair comparison. He was afraid Mr. Osborn was a little too late with the new treatment.

With regard to Mr. Cooke's remarks, that they must run slow and cut deep. That was very true in regard to removing large quantities of metal, but he immediately followed that remark with a speed analysis of work requiring very little off. It was necessary to run through very quickly with these cases, and to-day, the less material to be removed the better. Mr. Cooke also mentioned another matter, and that was the removal of the skin. There was no doubt about it, pickling was a most important subject in the matter of machining small castings. Although he (Mr. Daniels) had used high speed steel he could

only get a speed of 60ft. in the lathe, whereas he wanted 80 to 90ft. on cast iron, including the skin. However, they pickled those castings, and were able to get a speed of 80ft.

He was obliged to Mr. Hetherington for his remarks about the Committee, but he would like to correct Mr. Hetherington —the Committee might as well take full credit for what they had done. The Sub-Committee consisted of four members, including the President (who had worked as hard as anyone). The total number of hours came nearer to 1,000 than 800. Each of the Committee had put in from 300 to 400 hours. At least one of the members of the Sub-Committee had been at every trial, and sometimes two or more at the same trial.

With regard to the tool makers, which Mr. Hetherington thinks were so much to the fore, he (Mr. Daniels) had changed a lot of cones in lathes—some were old—but he had found it necessary, with this high-speed steel, to have more belt-power in the tools. That was a most important subject. He had taken the old cones out. Where there had been five speeds with 2½in. belts, he had replaced them by three speeds with 4in. belts, and so on, with very satisfactory results, the pitch of the teeth in the headstock wheels being well on the strong side.

Respecting the planing machines, there was a great necessity for quicker-running machines.

There was also another important point, viz., the failure on medium cast-iron. If members would turn to Table V., on page 280, of the medium cast-iron tests, they would notice the results were very bad, even with the tools tempered by the makers He had made an analysis, somewhat as follows:—

In soft steels, in all trials, there were 28 on each bar.

In soft steel	there were	19	successful	cuts.
In medium	,,	19	,,	,,
In hard	,,	15	,,	,,

In cast-iron, there were :—

19 In soft cast-iron,
9 only in medium cast-iron, and
24 successful cuts in the hard cast-iron,

showing the same difficulty with the tools prepared by the maker for medium cast-iron.

He did not quite agree with Mr. Day that these steels were all equal. Let them deal exactly with the facts. If they persuaded themselves that the tools were all right, and the tools were all equal, he thought the steel makers would stop there. One was superior to any of the others, more easily tempered and forged. He was not there to press anybody's steel. No later than that day he had tried one of the high-speed steels. He had it forged and tempered, and ground at both ends, so that if one end was not properly tempered, the other one, perhaps, would be. He put that in the rest to a pulley in the lathe 24in. wide, which was being turned. The tool ran ½in. across the face and then failed. He then tried the other end of the same tool. It ran for 1½in. across the face and failed. He then put another maker's high-speed tool in, and it went right across the surface, viz., the remaining 22in. The speed was 50ft. per minute.

Mr. C. Day said: The remark he made was not that all the tools were equal, but that several of them were about equal.

Mr. Osborn said: He was quite satisfied with the way the Committee had treated his firm. He was sorry if he had said anything that conveyed any other impression.

Mr. H. N. Bickerton said that as the other members of the Committee had spoken, he would like to take that opportunity of saying a few words about the tests. Mr. Osborn in his

remarks had raised the question of the tests made with Mushet steel. He, Mr. Bickerton, had had something to do with that matter, but he thought Mr. Osborn was looking at it in a wrong light. They had not tried the Mushet steel as a competitive test, if they had it would have been only proper to have done so after it had been treated by Mr. Osborn. They had simply taken the steel and treated it as they would have done in the works, and the tests were made principally to indicate the quality of the material they were dealing with. He did not think that Mr. Osborn need have any uneasiness in the matter, as the tests showed how much superior Mushet steel of five or six years ago was over ordinary steel, and he did not suppose Mr. Osborn would for a moment suggest that Mushet steel made at that period would compare with the high-speed or improved Mushet which Mr. Osborn was offering to-day.

It would be a mistake for him, Mr. Bickerton, to find fault with the tests, considering he was one of the Committee. Still, there were some points which might be better managed in future tests. In the first place, he thought there were far too many makes of steel tried. With fewer makes there might have been a larger variety of tests made. The materials operated upon were of course the more generally used ones, still it would have been an advantage to have tried other materials, or in any case, brass. They might also with advantage have made some tests as to the heat generated under different conditions of speed and feed. That was a very important consideration when accurate work was required, more particularly in boring cylinders, where if the cylinder got too hot it could not possibly come out perfect. This would apply also to piston turning and other work of a high-class character. Of course this was not a question of tool steel quite,—probably more a question of the shape of the tool,

but it was one that required to be gone further into. Tests on the shapes of tools also had not been sufficiently dealt with. It would occur to anyone who saw the variety upon the table, that some must of necessity be better than others. The fact that so many different shapes had been sent in showed that upon this point there was yet a lot to learn, it would be very advisable to try and get at the best.

There was one question which occurred to him in connection with using high-speed steel, and that was its adaptability to the making of different shapes of cutters. It was not always a straight bar that was wanted in the works, but very often a cutter of complicated shape to fit some particular holder. From his experience there was considerable difficulty in forging and mounting these special cutters.

Mr. Cook had made some mention as to dealing with castings. In his firm it was the practice to pickle all small castings where the skin only was required to be removed. With castings through which holes were bored, there was no doubt that annealing was the proper treatment, and this had been their rule.

Mr. Day had mentioned an important point, viz.: what is the relation between the materials used in the tests and every day workshop material? Unless some basis of comparison can be arrived at, it would be impossible to make a proper use of the information in the paper.

It was particularly with the object of conveying some idea of the quality of the material that the tests with ordinary water-hardened and Mushet steel were made. If the results of those tests are compared with the results usually obtained with water-hardened and with Mushet steel in our workshops we shall be able to form a fair judgment of the material operated upon in the tests. Mr. Bickerton said that in his opinion the soft cast-iron mentioned in the tests was much softer than was likely to

be used in ordinary work. The medium cast-iron, on the other hand, was much harder than is generally used for tools or engine work unless it might be in the case of liners for cylinders. The hard cast-iron was extremely hard; so much so that the ordinary steel positively refused to cut it at the lowest speed the lathe could be run at. Mr. Bickerton thought that the best results of the tests on medium cast-iron should be exceeded in ordinary shop practice with the usual run of castings. In fact, he did not think there would be any difficulty in doing so with any of the brands of steel which he, along with the other members of the Committee, had the opportunity of testing.

Mr. J. M. GLEDHILL (Armstrong, Whitworth & Co.), said he was present as a visitor, but with their permission he would say a few words. As the members knew, he was connected with a firm called Armstrong, Whitworth & Co., possibly the members had heard of that firm—they were makers of high speed tool steels, and some other things. He was very much interested in Mr. Saxon's remarks with regard to heavy cutting, and if Mr. Saxon would run over to their works at any time he would be happy to show him steel from anything between 2½in. and 8in. in section, doing comparatively as good work as the tests they had seen at the school here.

With regard to Mr. Hetherington's remark about machine tools and tool steel makers, as a tool steel maker, he would like to say that they were very much ahead of the machine tool maker; but being also connected with machine tool manufacturers, he thought they were ahead of tool steel makers, so that members would, perhaps, wonder where they were. He would tell them. They had found from experience, and not from anything else, that on going into solid facts they thought that the present tool steel had undoubtedly left machine tools high

and dry. His firm, as they knew, made armour plates, and turned the bolts for same, for some time past, at 80ft. per minute. They had always felt that they could work at a much higher speed, and turn out the bolts quicker, if they had a more powerful machine. That very day they had started a new and more powerful machine, designed by their machine tool branch. He saw it operating that morning. It was taking a cut $\frac{3}{4}$in. deep and the speed was 130ft. per minute, the traverse was about $\frac{1}{32}$in. and the section was about $1\frac{1}{4}$in. To show the comparison—they jumped from 80ft. per minute on the old machine to 130ft. per minute on the new machine. The width of the belt was 8in. and the height of the centres 12in., so that the members could easily see there was a little strength behind that machine.

With their heavy cutting tools they would have been very glad if the Committee would have taken heavier cuts, as Mr. Saxon suggested, and his firm would have been most happy to have lent them a lathe for this heavy cutting. Such a lathe, however, would have weighed about 100 tons or so, and although they were able to do most things at the Technical School they might not yet have a crane suitable for handling such a lathe. However, by the time Dr. Nicolson read his next paper he hoped he would have one of their heavier lathes for his work.

With regard to Mr. Hetherington's remark as to the position of the tool steel makers and the tests. It was not his intention to advertise the firm of Armstrong, Whitworth & Co., they never advertised, and they were not going to begin; but they were most willing, when they were invited to submit tools for testing purposes to do so, simply for the purpose of getting scientific results and facts, and as to what other people's steel would do, they had not given any thought whatever. What they did was to put their shoulder to the wheel on this tool

steel question, and they said to themselves "We will submit the very best materials we can do, and we hope to come out satisfactory." So much for that point. He would not have referred to comparative results, but Mr. Hetherington had brought the matter up. He (Mr. Gledhill) would just read out the two firms Mr. Hetherington had alluded to, and he thought when he had read out his figures, which were taken from the Report, it would leave little doubt Mr. Hetherington's statement was not exactly correct.

In the first place, taking Messrs. Armstrong, Whitworth & Co. They had only two failures altogether, they lost 27 minutes, their cutting speed average was 50·4, and the weight of metal removed was 1,851lbs. Their figure of merit was "1."

Next, taking Messrs. Firth's. They lost 100 minutes as against their 27·5, the average cutting speed was 46 as against their 44, the total weight of metal removed was 1,772lbs. as against 1,851lbs. He thought they might therefore be pardoned in saying that they had the honour of the first position in these tests, and he was sure, as a Manchester firm, it was an honour they were very proud of.

With regard to Mr. Osborn's remarks on the question of Mushet, he did not think the Committee had any intention of doing anything against the brand known as "Mushet." They took that as a high standard tool steel after the ordinary steel, and no doubt that steel had had a great career.

Then Mr. Webb had raised a very important matter in regard to planing and drilling with high speed steels. He would give the figures his assistant handed him of things which had actually been done.

Cast iron. - Planing bed plates. (Taking the hardest first.) Speed 40ft. per minute, $\frac{1}{8}$in. traverse, $\frac{1}{16}$in. depth of cut.

Another case was that of a flywheel cutting with the skin, as cast. Diameter of wheel 24ft., speed 32ft. per minute, depth of cut $\frac{5}{8}$in., traverse $\frac{1}{4}$in., tool went across the flywheel with skin on.

Another case was a flywheel 5ft. 9in. by 14in. broad. Speed 65ft. per minute, $\frac{1}{4}$in. cut., 12 cuts per inch, tool finished in good condition.

Then they had the question of drilling, and the following were a few figures they had drilled:—A $\frac{3}{4}$in, diameter drill, acting on a block of cast iron with scale on, 4in. thick, running at 360 revolutions drilled 187 holes before re-grinding.

The next was their record case:—With an "A.W." Twist drill $\frac{3}{4}$in. diameter, 525 revolutions per minute they bored through a 4in. block in 18 seconds, or equal to 13·2 inches per minute.

These were, all would agree, remarkable results.

He greatly appreciated this Report of Dr. Nicolson, and they had all to congratulate the Committee. He was inclined to offer them his sincere sympathy over those 800 hours they had put in over the tests, and if he had to fix their rate of pay, he would certainly give them "overtime rate," they deserved it. Everyone knew that the tests had been carried out in a scientific manner, and the reason they had been carried out so thoroughly was that the Committee were engineers and practical men and as such knew what they were about and what they wanted to discover.

It only dealt with solid facts, but they had still a lot to learn, and he agreed with Mr. Saxon that it would be a misfortune if they arrived at any final stage. He did not believe in finality, and although they had made some splendid results in these tool tests, they must not rest content on their laurels, but go on with the research just as though they had done nothing, so to speak, and who would say, when

they perhaps knew better the chemical combinations and association of metals and alloys in steel, such as nickel, chrome, tungsten, molybdenum, titanium, uranium, etc., that they might not have even better results in a short time from now than they had already obtained.

He thanked the members very much for their attention, and also his assistants who had worked so loyally with him.

The PRESIDENT here read a letter from Mr. Orcutt, of the firm of Ludwig, Loewe, and Co., as follows:—

Dear Mr. Constantine,—I have to thank you for your great kindness in sending advance copy of report on high-speed steels. This report is of very great interest and value, and you have done a very good work for all engineers in getting together this material. Let the good work go on, and take up milling, drilling, and planing tests. We are all at sea on the matter of high-speed steels—the power required for working them and the best feeds and speeds. Lathes tests are certainly the most important, but I am beginning to think drilling tests are also of extreme importance. It is more difficult to get good cutting tools, in the form of drilling and milling tools, than in lathe or planer tools. I hope, however, you will see your way, in connection with the Manchester Technical School, to carry out tests also with milling, drilling, and planing. You would find, especially in drilling tests, most astonishing results with high-speed steels. It seems to have no difficulty whatever in drilling a hole of 1in. diameter, with a feed of 6in. to 7in. per minute, in ordinary cast-iron. The amount of power required, also, is astonishing, and all goes to show that machine tool makers have a tremendous task in front of them, and if you can carry out complete tests, it will be of the greatest value.

Referring to Tables, may I suggest, that if you add to Tables XIII. to XVIII. inclusive another column, under the

heading, "Intended Cut and Traverse," these Tables referred to would be much more comprehensive.

I regret exceedingly that I cannot be at the meeting on November 7th. I think the discussion will be interesting and valuable.

I should esteem it a great favour if I could secure of the report, when it is ready, a dozen copies, to distribute among our engineers in our works. Of course, I would be glad to pay for these.

With kind regards, yours sincerely, H. F. L. Orcutt.

The President continuing, after reading the letter, said he would like to clear up one or two points. There was the subject of "chatter," and someone had asked what the "finish" was. Where the tools had gone through, with a few exceptions, the finish was good. Of course the mark of the tool was left, showing the traverse which had been used, but with the exception of a few of the heavier cuts the finish was all right. The heavier cuts chattered with some of the tests which took place, but they found that synchronised with the back lash in the gearing and a slight increase or reduction of the speed in most instances was sufficient to eliminate the chatter. Tools of heavier section had been referred to as being capable of removing more material. Why was it? Why should they? Was it due to the larger mass of steel carrying off the heat from the cutting edge more quickly, or what was it? There was no doubt about it, this question of removing material with double tools was one which it would be well to investigate further, and also the tool which Mr. Saxon had mentioned with the double cutting edge. There appeared to be something good in that.

Then with regard to tool steel makers, they would very materially assist tool steel users if they would be more explicit

in their instructions with regard to the use, forging and cooling of their steels in the shop. Some of the instructions were not at all clear, an ordinary intelligent smith would be left somewhat in doubt.

Another point had not been referred to, and that was the lubrication of the cutting edge. What the effect of that was they did not know, it had not been tried in these tests. He would like to lay down with emphasis that the results of these tests had, in his opinion, been such as to prove that practice agreed with science to a much greater extent than was often the case in general engineering. They had several instances which the members would notice in studying the curves and the deductions which had been made, in which practice, although it had led them to a contrary opinion to the one generally held, strongly coincided with science. He would have liked to say more on this point had time permitted.

Mr. Webb had raised one point. They would be glad if any members present, or visitors, who had anything they would like to add in writing to the discussion, subject to the approval of the Committee, that they would be very pleased to embody it in their transactions.

He would now ask Dr. Nicolson to reply briefly to the discussion, and what he was unable to give a verbal reply to perhaps Mr. Adamson might be able to help him out, and if Mr. Adamson could not, he would ask Dr. Nicolson to deal with it in writing.

Dr. Nicolson said he had been rather relying on Mr. Adamson to reply to the discussion, and he had, consequently, been taking things rather easily. There were, however, one or two points upon which questions had been asked that he was ready to reply to.

One was, how was the degree of hardness arrived at? The degrees of hardness given in the paper were only relative figures. These were not in any sense absolute. There was at present no universally recognised standard of absolute hardness. They had, of course, the old method of arranging substances in the order in which they would scratch each other. Professor Martens, of Charlottenburg, had made a long series of experiments on this subject. He had devised several different designs of instrument for determining relative hardness. One machine consisted of means for making a carefully mounted diamond-pointed tool scrape little grooves in the surface of the material to be tested. In one method he used a microscope with a micrometer eye piece to measure the widths of the grooves made by the diamond tool in different materials. In another he weighed the cuttings or dust removed with a delicate balance, and compared the results thus obtained. All such methods, however, gave results which were relatively different, and it was a very difficult matter to arrive at an absolute standard.

The machine they had used was simply a reproduction of a method already adopted. They had fitted a small drilling machine which happened to be available, with a scale pan to weight the spindle, and mounted an indicator barrel so that its rotation showed the depth drilled and the motion of a pencil parallel to the axis of the barrel indicated the number of revolutions made by the spindle in drilling to this depth. Thus they obtained autographic records whose slope indicated the hardness of the materials drilled.

There were other points he might have referred to, but he thought he had better sit down now so as to allow plenty of time for his friend Mr. Adamson.

Mr. Daniel Adamson said before commencing to reply to the discussion which had taken place, there was one reflection cast

upon the Committee at the last meeting that he would like to defend them from. One speaker had said that the Committee might not have done any work unless the Honorary Secretary had looked after them. He would like to here state that each member had taken his share quite equally in connection with these experiments.

They had each had their own ideas as to the results to be shown by these experiments. He personally had been anxious to see some connection between the actual speed obtainable and the cross-section of the cut being taken. This connection was shown by Plates III. and IV. If they had a given class of work in their shops, and a given quality of iron-castings or steel forgings, they could easily ascertain how much slower they would have to run if they increased the weight of their cuts and quickly ascertain from the results now published the advantage of so doing if the work and the machine would stand the heavier cuts. They had however been disappointed in trying to find some relation between the possible cutting speed and analysis or drilling hardness of the materials. He thought the members would understand from what Dr. Nicolson had just said that it was a difficult business to base any estimate of possible speeds upon the hardness. They were in hopes that an analysis would have helped them but they were disappointed here also with regard to cast iron; but Plate XI. gave them some guidance with regard to steel forgings.

With regard to Mr. Saxon's experiments the results were what he might have expected from the data given in the Report. The power taken under the two conditions, one tool having the whole cut, or two tools having a divided cut between them, was the same if the speed was the same, but the two tools could remove 50 % more material than the single tool; that was to

be expected from the results given in the Report, if the tools in each case were worked up to their full capacity. Mr. Saxon's experiments were a confirmation of the Report. He thought that Mr. Saxon had omitted to say that the material he operated upon was medium cast iron.

With regard to Mr. Hetherington's comparisons, the results given in the Report might be looked at in a great many different ways, but the Committee had carefully abstained from making any comparisons between the different brands of steel. It was however of interest to observe that every firm was represented amongst the best results of the trials in Table XIX. Mr. Hetherington made a criticism of experiment 26, but it was not correct to speak of it as an endurance trial, it was explained in the paper that it was a special trial to ascertain the power that could be transmitted by the belts. It would however be advisable to record the ratio of back gearing in use during the experiment. Mr. Hetherington had expressed disappointment at the average weight removed during the whole of the experiments, but he would explain that most of the trials were with very light cuts; if it had been intended only to show the maximum weight removable they would have chosen cuts something like $\frac{3}{8}$in. by $\frac{3}{8}$in., which would have removed about 20lbs. of material per minute, but then they would not have been able to show the very interesting comparisons between area of cut and other conditions referred to in the Report.

One speaker had raised the question of "finish" to be obtained with the steels, and that seemed to be a matter upon which more light might be thrown by further experiments. Speaking from his own experience in their own works, they had tried two small pieces, with the same traverse and the same speed, with the ordinary steel, and with high speed steel, and on feeling the same afterwards, it was found that the piece cut with the high speed steel was much rougher than that cut

with the old steel. The old steel possibly acted more as a burnisher than the new steels.

As Mr. Day had stated, they avoided all comparisons between the various brands tried. Mr. Hetherington had remarked that no names were mentioned in connection with the endurance trials. There were no tool steel representatives present at those trials, therefore they did not think the tool steel makers were responsible for the results obtained, so they omitted their names to prevent unfair inferences being drawn. These tools were forged and tempered in the School, to printed instructions given by the makers, so that the Committee could satisfy themselves that there was no secret in the tempering, and for the same reason the opposite end of each tool was taken to that which had been prepared by the makers and used in the main trials.

Mr. Day remarked as to "chatter." They had had some trouble with vibration during the experiments, but it appeared to them that it was a question of synchronisation between some of the gearing and the revolutions of the lathe, as varying the speed checked the vibration. The results of the trials clearly proved that the cutting stress did not increase with the speed, but of course the power to be transmitted by the machine increased and therefore machine tools would, no doubt, have to be built stronger in the future on the "anvil theory."

With reference to the means to be adopted on machine tools to obtain a suitable variation in speed, in the speaker's own works they varied the speed of some of the machines by means of the directly attached motor.

Mr. Webb had asked what other problems had forced themselves upon the notice of the Committee. There were several of these, such as tool angles and shapes, effect of grinding on grindstones or emery wheels, etc.

As to removing the skin, they could not make any comparative experiments, because there was not enough skin. Speaking from his own experience, if the tool point was under the skin, the effect did not seem as disastrous as it would be if there were hollows in the casting, causing the tool to rub, when the higher speed of the job caused it to rub as a very efficient grindstone.

Dr. Nicolson had replied about the standard of hardness. As to what constituted hard and soft in steel, they had a very fair idea from the analysis. That was fairly well known amongst steel makers. They took the makers' advice with regard to the hardness of the castings. They asked in the first instance for a medium casting, such as would be used for machine tools, and later for a harder and a softer casting. The different analyses and physical tests were given in the report, and Mr. Bickerton had also made some remarks in his reply on the same subject.

As to how long a tool might be kept in, they did not know where to draw the line. They had one tool in their own works which lasted a fortnight without grinding. That meant the machine should be speeded up, but they had not yet been able to do this.

With regard to Mr. Osborn's remarks, he had perhaps overlooked the fact that the original instructions for working ordinary Mushet steel were that, if you overheated the steel you would spoil it. Now, the instructions were that if they were to heat it more it would do better.

Mr. Gledhill gave some figures, and had mentioned "a figure of merit." That was Mr. Gledhill's own figure. The Committee had assigned no figure of merit to any of the tools or firms. There was one figure given in the tables, which was perhaps misleading Mr. Gledhill, and that was the figure given in column 17 on the right-hand side of Tables I. to VI., which

shows the relative condition of cutting edge of tool after the experiment. After the seven or eight tools had gone through their particular series, they arranged them according to the condition of cutting edge, so that if one tool had done more work than another, they could also ascertain whether it was in as good condition after it had done so as the tool that had not done so much. They must however, take the condition of cutting edge as only one item in the whole comparison The speed and weight removed had also to be considered.

Mr. Gledhill gave some figures of the speed of drilling. They (the speaker's firm) had tried what they could do with the ordinary old-fashioned twist drills that were made before the high-speed steels were heard of. They drilled through a steel plate at the rate of 8½in. per minute with ⅝in. ordinary drill. They drilled 14 holes before they had to grind, and the plate was ½in. thick. He concluded therefore that they did not know in many instances what could be done with the old steels, whereas the new steels were at once tried at their maximum speeds and the results quoted.

The Committee felt, as Mr. Gledhill had said, and as Dr. Nicolson said at their meeting a fortnight ago, that this report was only a beginning. It was something that anyone could now take as basis in carrying out further experiments, either for themselves or publicly, and he suggested that there was a very good opportunity now that the lathe was at the school, the material was there, Dr. Nicolson was available, and some members of the Technical School Committee were also present at this meeting, all the facilities were there for a continuation of the experiments. These further experiments were very desirable, because although they knew something of the matter of cutting speeds they knew nothing about the best angles, or how cutting stress affected cutting speed. There were many other points which might be enquired into if further experiments of this

character were made, and they could find another committee who were willing to put in a further 800 hours, and if they could persuade the school authorities to allow the experiments to be carried on. Mr. Bickerton thought they had asked too many tool steel makers. The market was very different now to what it was two years ago when the firms were invited. If they had left any out they might have left out a good one. (The President here remarked that some people said they had left out the best now).

With regard to the uses of high speed steel, there were several matters which might be considered. Were they suitable for taps and hack saw blades, etc.?

Mr. Orcutt's letter mentioned drilling. Some elaborate papers had been published in a French journal, "Arts Mécaniques," on drilling, by M. Codron, but he had not waded through them yet. They were very elaborate, considering they were only based on drilling. From Mr. Orcutt's letter, it was evident that the question of rapid drilling was comparatively new in Germany, so that he was glad that in that respect they were somewhat ahead of their foreign neighbours, judging by the results Mr. Gledhill had quoted.

There was another point. He gathered from an American paper that milling cutters of high-speed steel were a new experience in America, so that he was glad they were there also a little ahead of their other neighbours. Milling cutters were already in use here, and some of the members present could speak very readily on this point.

In conclusion, Mr. Adamson said they must only take the report as a basis for further deductions, and not as a hard and fast rule for making comparisons, as improvements in tool steels were being made continuously.

Mr. James Saxon said: Before the meeting terminated he would, at the call of the President, like to move that a vote of

thanks be tendered to Mr. J. H. Reynolds, on behalf of the Municipal School of Technology, for the use of this splendid lecture hall. At the same time, he would like to urge upon the Technical Instruction Committee the advisability of proceeding further with these tests, in connection with which he felt sure their own Council and Association would loyally co-operate, as in the tests under consideration this evening. They had already arrived at very valuable conclusions, so far as the tests had gone, and it was necessary that these conclusions should be strengthened by additional investigation. He was sure they were all pleased at the mutual co-operation which had existed between their Council and the Technical Instruction Committee, and also between the members of the Joint Committee, comprising their own members and members of the School of Technology Sub-Committee, together with Dr. J. T. Nicolson. He was sure it was a pleasure where two bodies could co-operate with such a useful object in view, such as these tests furnished. He felt certain the Joint Committee itself had only just found out what they really wanted to know on this particular subject, and if those experiments could be permitted to proceed further, no doubt Dr. Nicolson and his excellent staff would be able to produce more exact curves and plottings for their diagrams of work done, the formulæ resulting from which would reduce this branch of their investigations to a more exact science than formerly. They had already heard from the members of the Joint Committee that they now know what they want to know, and he believed that the expenditure of a little more time and money, both of their own and the Manchester City Council's, were all that was necessary to achieve further important results. He felt that they only needed to make the suggestion to the Technical School authorities to ensure their hearty co-operation in the matter.

By the kindness of Mr. Gledhill, of Messrs. Armstrong, Whitworth & Co., the Committee were already assured of the further use of the lathe, which had been so kindly lent by his firm, and he believed also the material required to be operated upon. He felt they ought to urge upon their own Council and the Joint Committee who had taken these operations in hand, to strive with their utmost endeavour to proceed with the experiments to a further extent, in order to achieve more valuable information. They, the members of that Association, were sending their sons and apprentices as students to that School to be educated up to the latest attainments in Engineering Technology. He believed if the present experiments were improved upon, and circulated throughout England and the engineering world, they would be used as a basis of calculation and reference by engineers for some time to come, and would absolutely demonstrate the utility and value of such a magnificent Technological School as we in Manchester are possessed of.

The PRESIDENT said: He would ask the members to accord their appreciation *pro* Mr. Reynolds for the use of that room. The vote was carried with acclamation.

The PRESIDENT, continuing said: They had present Mr. Hiller and Mr. Nasmith of the Technical Instruction Committee, Mr. Hiller was at present Chairman of the Joint Committee, and he would be glad to have some expression from them with regard to further experiments.

Mr. E. G. HILLER said, in reference to the question of carrying out further experiments, personally he (Mr. Hiller) looked on these experiments as being incomplete on the scientific side at any rate. On such questions as the best form of tools

and the angle of cutting edge they seemed to be open to considerable development. If the Manchester Association of Engineers were desirous that these matters should be further investigated, no doubt considerable value would be attached to their opinion by the Committee who would have to decide this matter.

Dr. NICOLSON'S reply to discussion on behalf of the Committee.

Taking up questions in the order in which they fell from speakers, and which had not already been replied to, they had first Mr. E. P. Hetherington's point regarding experiment No. 26, Table VIa. With regard to this it was mentioned on Page 245 of the Report that this experiment was a heavy cut specially taken for the purpose of testing the driving power of the belts. It was not intended to be a durability trial of the tool, or a trial to remove maximum weight of material, and the lathe was stopped after a run of 5½ minutes.

Mr. Hetherington was disappointed that there was not a more striking difference in the results obtained with the different steels as regarded weight removed per minute. This seemed to show that the speeds selected by the different makers were all very near to the highest possible.

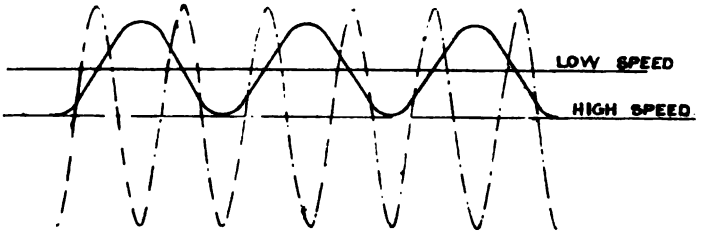
Mr. Charles Day had expressed the fear which had been felt that the results of the series of trials would be such as to lend themselves to advertising purposes; a result which the Committee expressly wished to avoid in this instance, where the information sought was for the general benefit of steel makers and steel users alike, and where the expenditure of money could hardly have been sanctioned by the City Council if some one steel maker were likely to reap an undue advantage.

Such objection would not, however, hold in a general way. It would surely be a mistake to refuse to make a research of

scientific or industrial interest simply on the ground that the results were to be used for advertisement. Provided the client paid the cost of the experiments there could be no objection to an engineering college undertaking such a research. Incidentally the client would be advertising the college! In America, indeed, the extensive series of industrial researches undertaken by the Polytechnics were largely the very foundation of their prosperity, as the wide circulation of the results made them known, enhanced their reputation, and directly contributed to swell the number and improve the quality of their students.

Mr. Day had given expression to his feeling of doubt with regard to the correctness of the conclusion which the Committee had reached as to the effect of the variation of speed upon the force required for cutting. He was of opinion that this force increased at high speeds, contrary to the results of the report. Perhaps, however, the force which Mr. Day had in mind, viz., that required to produce spring or chattering was different from the numerical force which the Committee had given in their tables; and from that point of view both might turn out to be right. The numbers representing cutting force recorded in the report were the values of the average force overcome at the tool point by the rotating work; and this *certainly* diminished with increasing speed. But the force producing chatter depended not upon this average force but upon the difference between the greatest and least forces operative during cutting, and this difference was probably greater at high than at low speeds. Thus although the average force was less at high than at low speeds, not only might this difference be greater at high speeds but the *maximum* force might also be absolutely greater than that at low speeds. The annexed figure would perhaps render this clear. The wavy curve, shown full, indicated the range of variation of cutting force above and below the average at low speeds, whilst the dotted curve showed the same variation for

high speeds of cutting. At high speeds also there was more likelihood of the time of vibration of the slide-rest, &c., falling into step with the period of the above variation of force, and thus allowing forced vibrations to be produced and maintained.



From this it would appear that those parts of the machine-tool, such as the belt, which were subjected to stresses depending only on the average cutting force would not need strengthening for high speed cutting; whilst those parts such as the bed and slide-rest which were exposed to the greater force variation due to high speed running would require increased rigidity in some lathes.

On the whole these considerations lead to the conclusion that the output cannot be much increased upon most existing lathes. For even granting that they possess the required rigidity, Mr. Day's suggestion of speeding them up could not carry them very far unless the belts were now running at very much below their proper speed. The work in the lathe also had to be considered; for it also had a natural period of vibration which was generally very small, and it would be more likely to synchronise with the time of variation of the cutting force at high than at low cutting speeds.

Mr. Cook had given some valuable data regarding the effect of pickling and annealing castings on the durability of the tool. It was pleasing to find that the practical information which the Committee were able to impart so nearly coincided with what the old mechanics had told Mr. Cook in his apprentice-

ship days. There was, however, one point in which the Committee would wish to differ from the "old mechanics'" motto of "run slow and cut deep," for they would rather say, as the result of their experience, "run *fast* and cut deep."

Mr. Cook's remarks regarding hardness had already been adverted to. It might be added that although the hardness experiments the Committee had made were not very comprehensive in scope, they had still given *some* information as to the relative hardness of the experimental bars and ordinary shop castings. Referring to Table XXIII., and to the column of hardness figures there given, the standard specimen referred to was a block of cast iron obtained from a foundry and called "medium." It might, therefore, be assumed to represent the material of a large proportion of machine shop castings. The figures of hardness in the table given for this material with a certain drill was about 4·74 (excluding experiment 4, where the drill had obviously been blunted by experiment 3). The same drill gave 3·84, 5·02, and 9·00 for the Whitworth soft, medium and hard cast irons respectively.

With another drill the above standard block gave a hardness figure of 4·20; compared with which they had 7·06, 7·06, and 8·46 for the Whitworth soft, medium, and hard fluid-pressed steels respectively.

17 Plates follow, illustrating this Paper.

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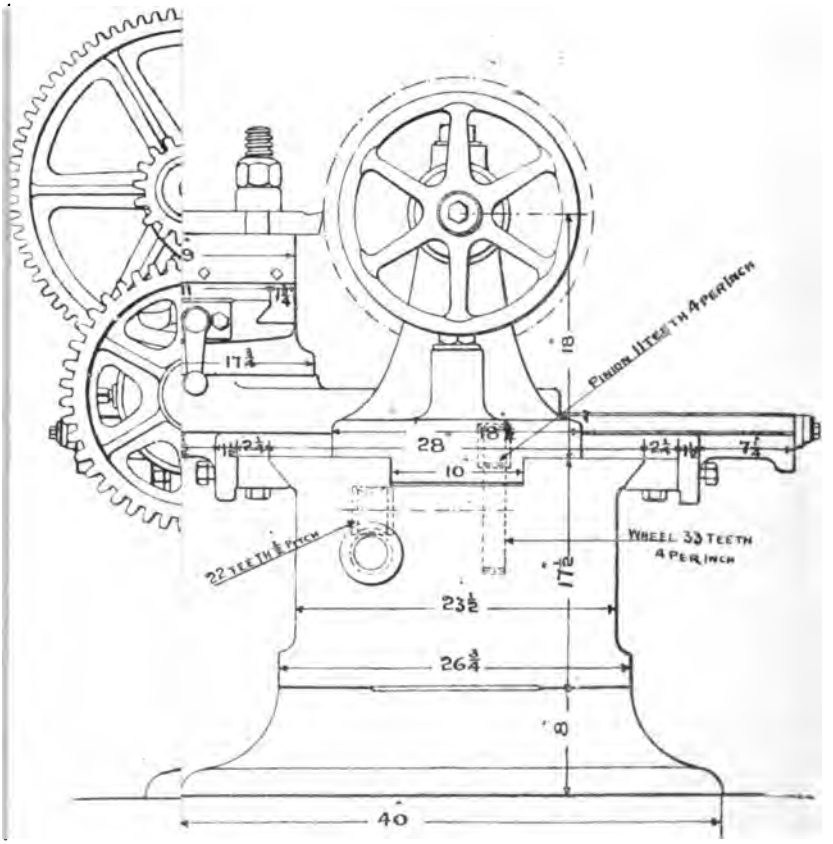
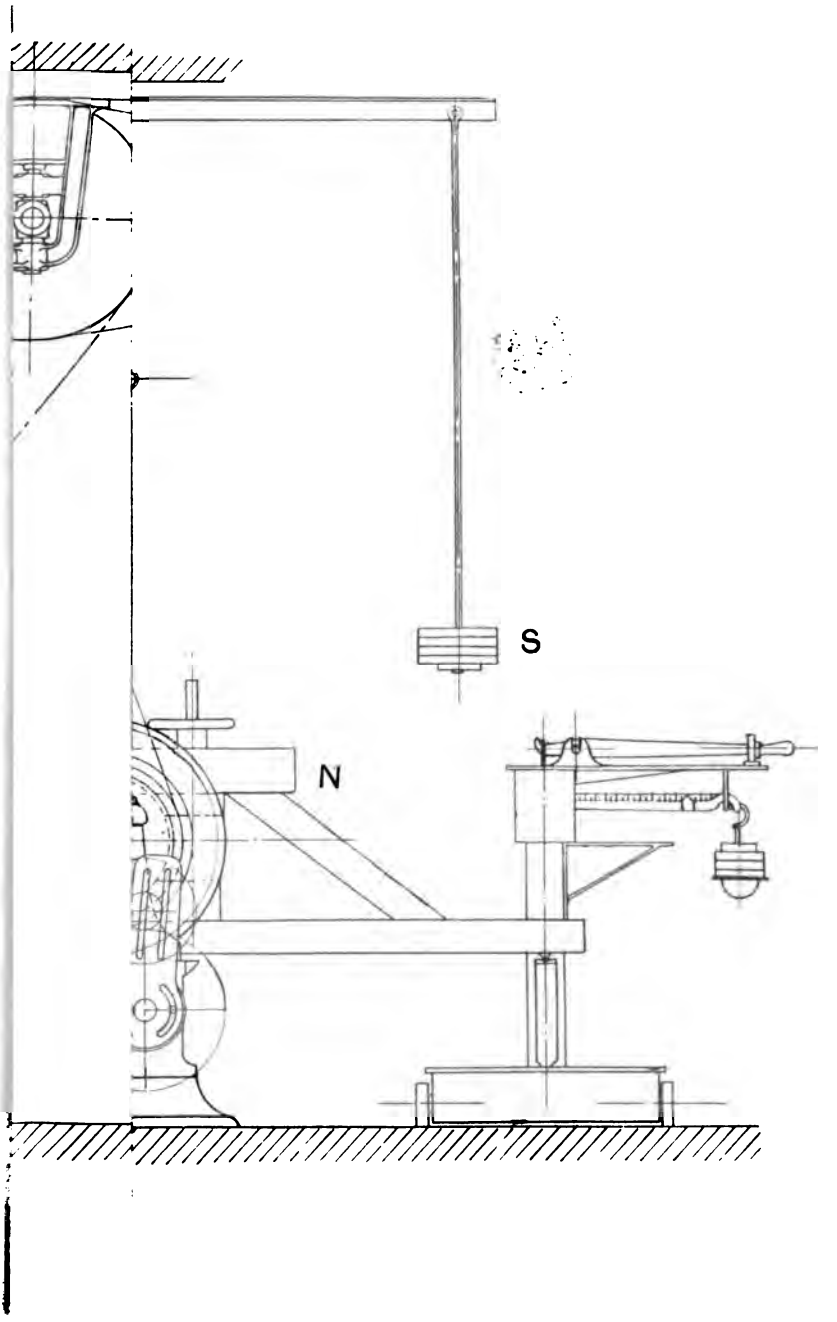
REPORT


PINION 11 TEETH 4 PER INCH
WHEEL 33 TEETH 4 PER INCH
22 TEETH PITCH
28
10
18
17½
23½
26¾
8
40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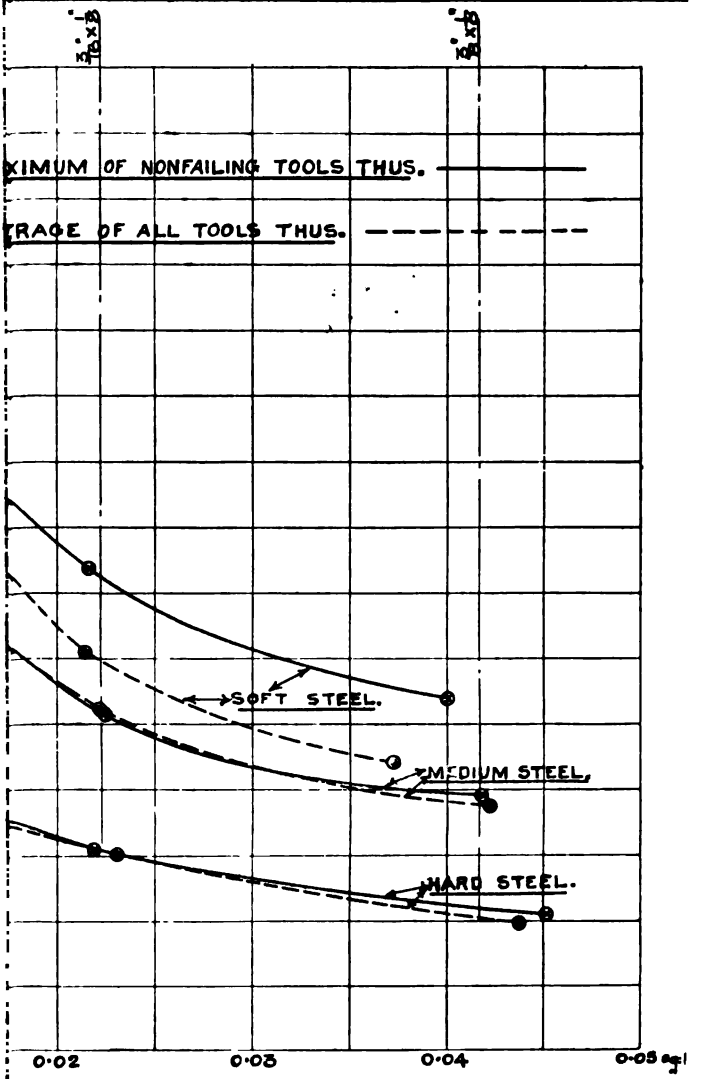
N

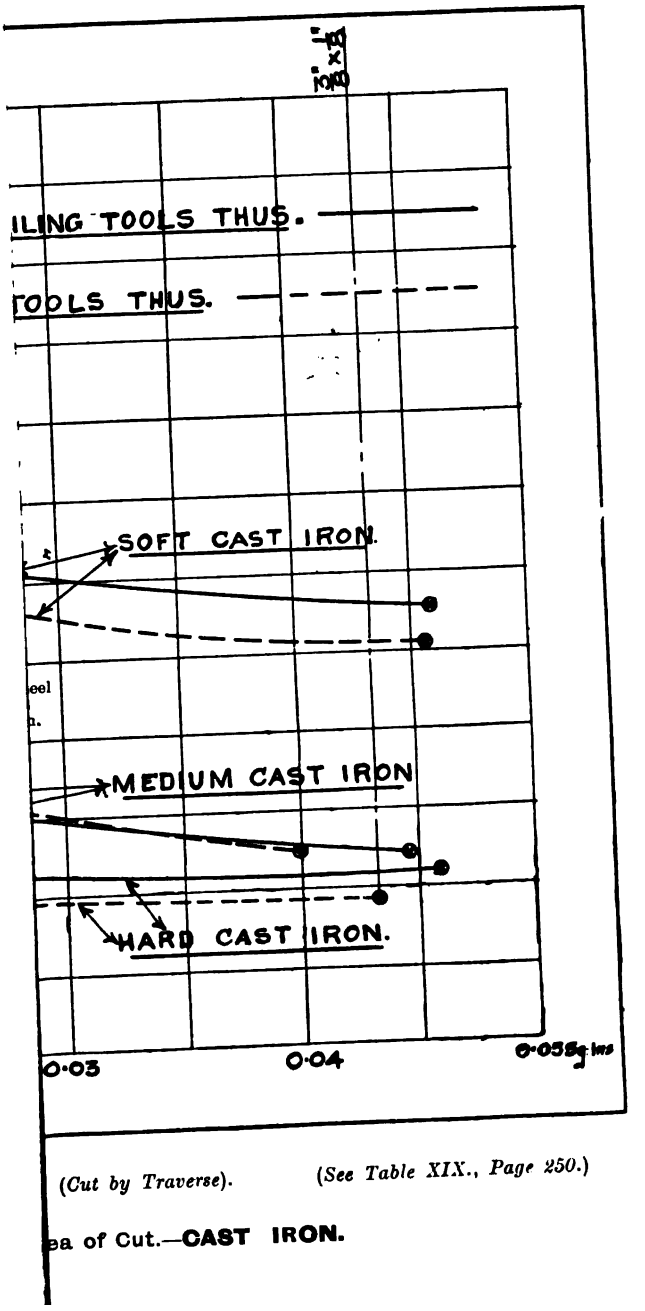
TS WITH RAPID CUTTING STEEL TOOLS.



EA OF CUT. (*Cut by Traverse*). (*See Table XIX., Page 250.*)

tting Speed with Area of Cut.—**STEEL.**

APID CUTTING STEEL TOOLS.



(*Cut by Traverse*). (*See Table XIX., Page 250.*)

ea of Cut.—**CAST IRON.**

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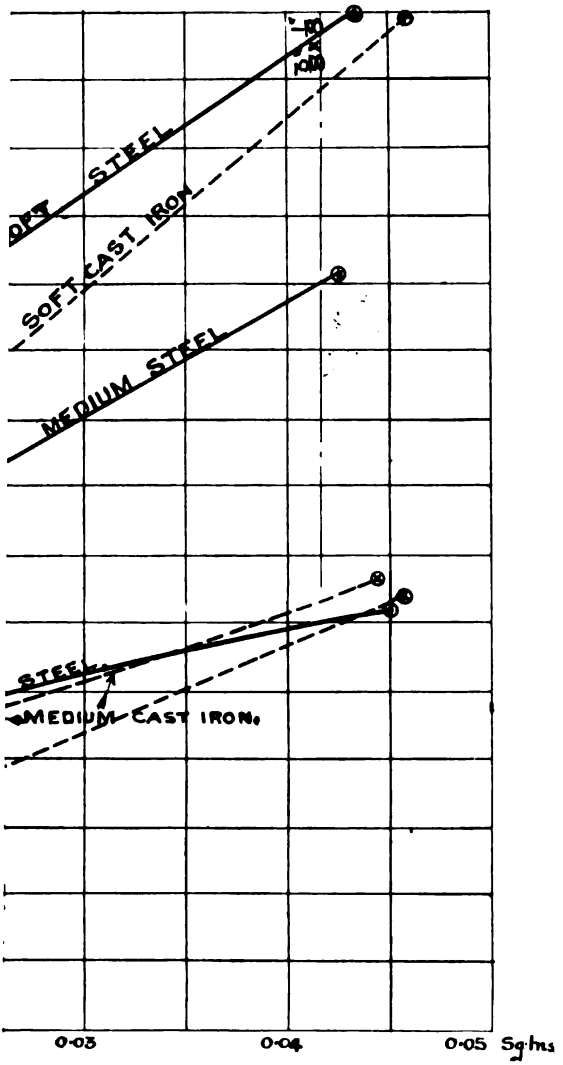
APID CUTTING STEEL TOOLS.



(*Cut by Traverse.*)

d per Minute and Area of Cut.

non-failing Tools.)

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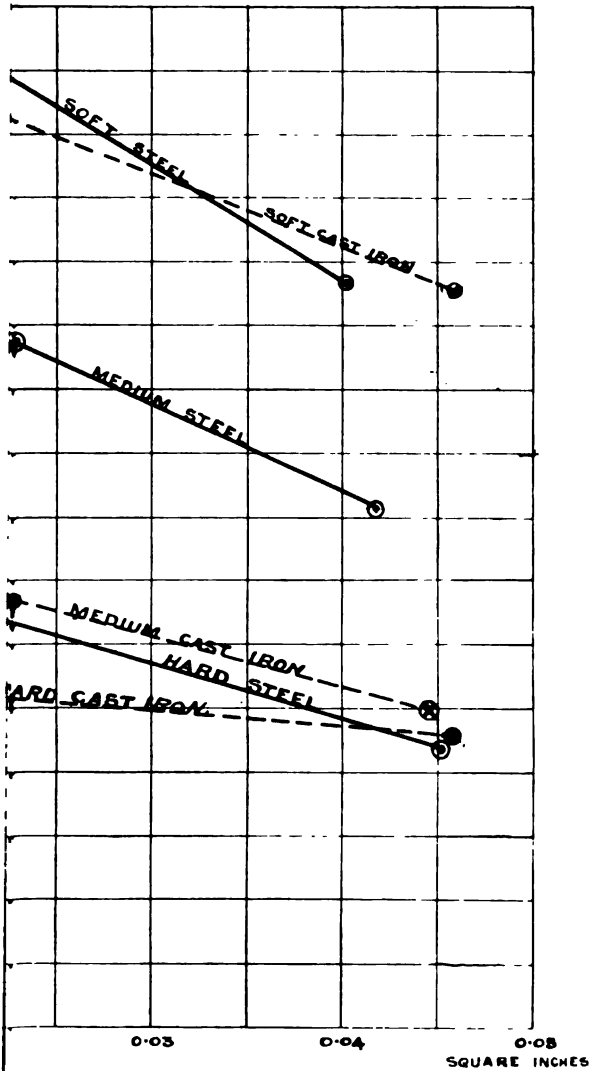
Plate VI.

TH RAPID CUTTING STEEL TOOLS.

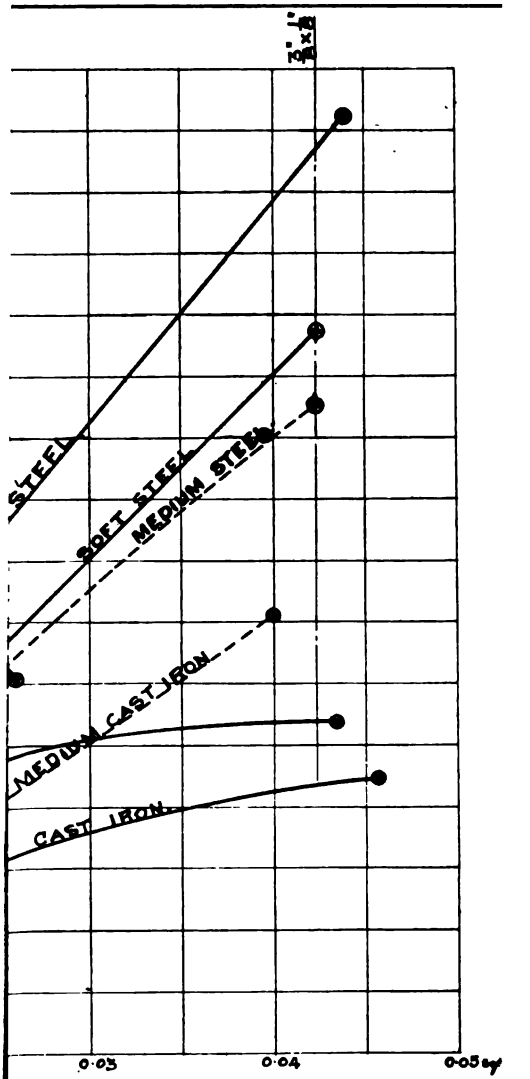


T. *(Cut by Traverse.)*

hined per Minute and Area of Cut.

Plate VII.

RAPID CUTTING STEEL TOOLS



(*Cut by Traverse.*)

ea of Cut for all Materials used.

m *Electrical Measurements.*)

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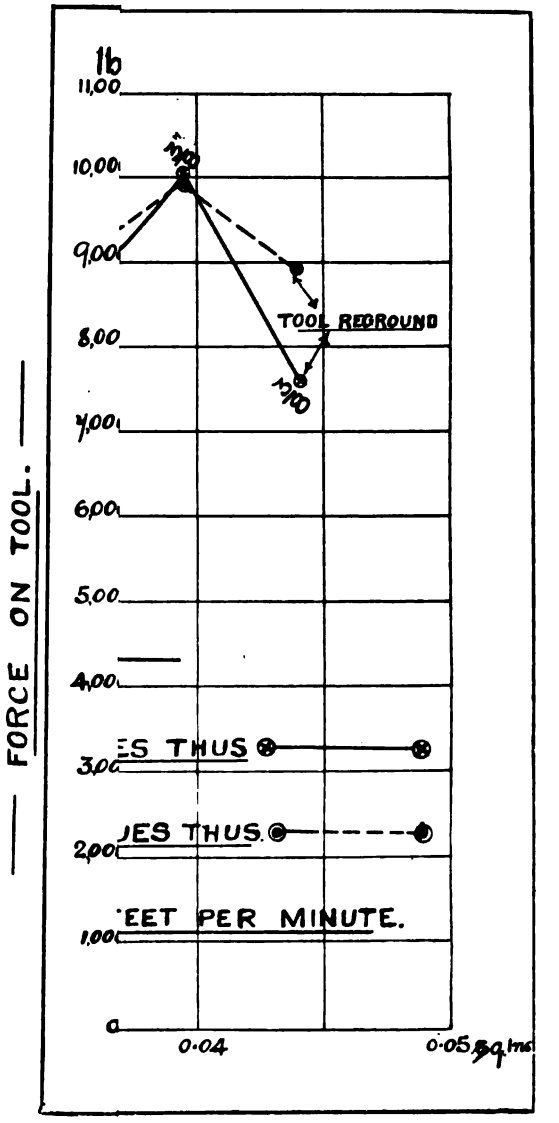
Plate VIII.

EEL TOOLS.



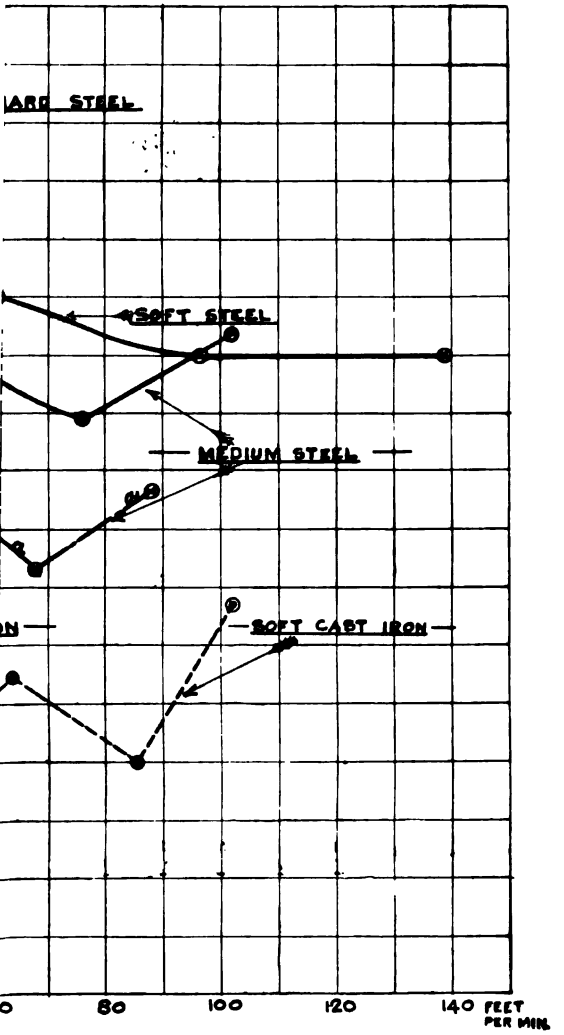
ynamometer on Lathe.)

MANCHESTER ASSOCIA

UNIV OF MICH.

Plate IX.

'ITH RAPID CUTTING STEEL TOOLS



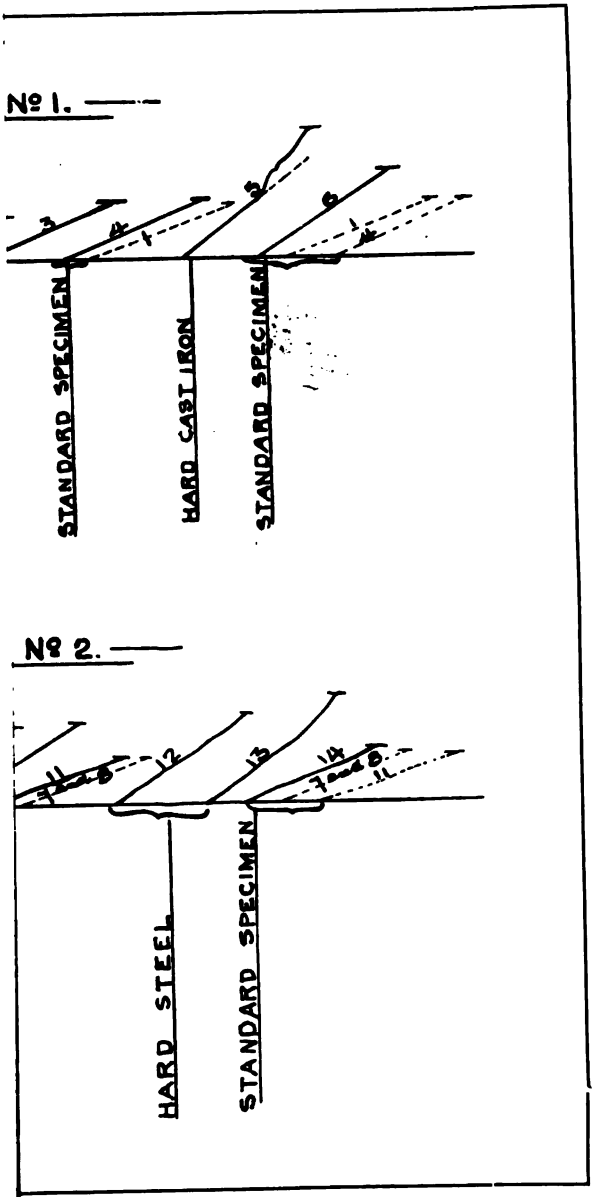
CUTTING SPEED. Values obtained from Dynamometer on Lathe, thus a— · —a, b——b

ting Stress with Cutting Speed.

from Current Measurements.)

Plate X.

WITH RAPID CUTTING STEEL TOOLS.



ardness Diagrams.

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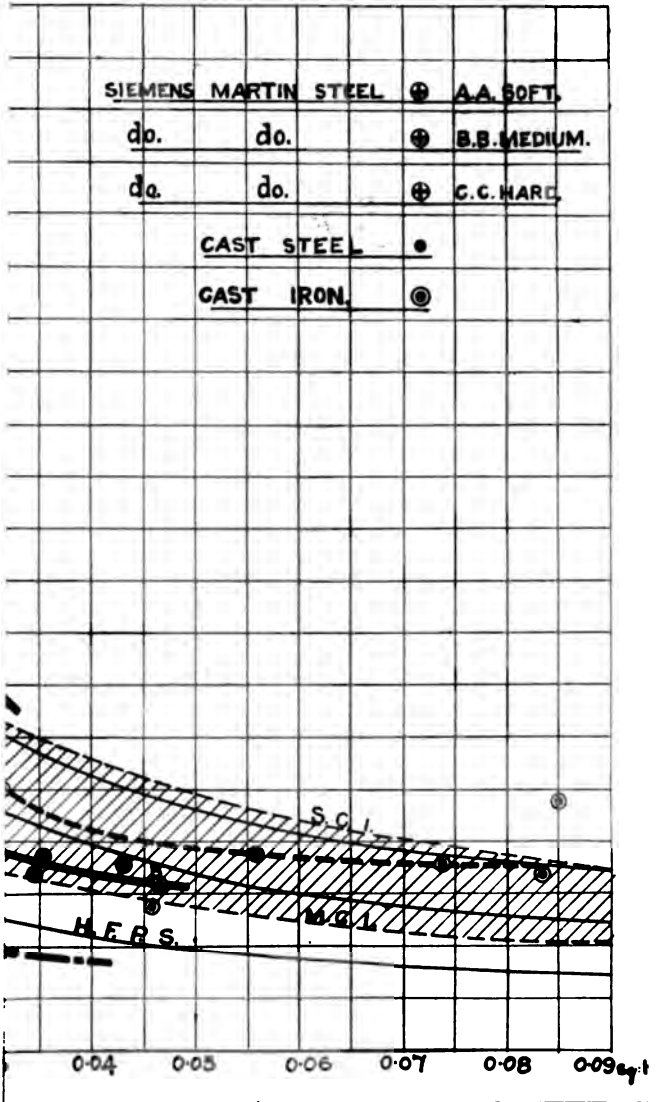
'S WITH RAPID CUTTING STEEL TOOLS.



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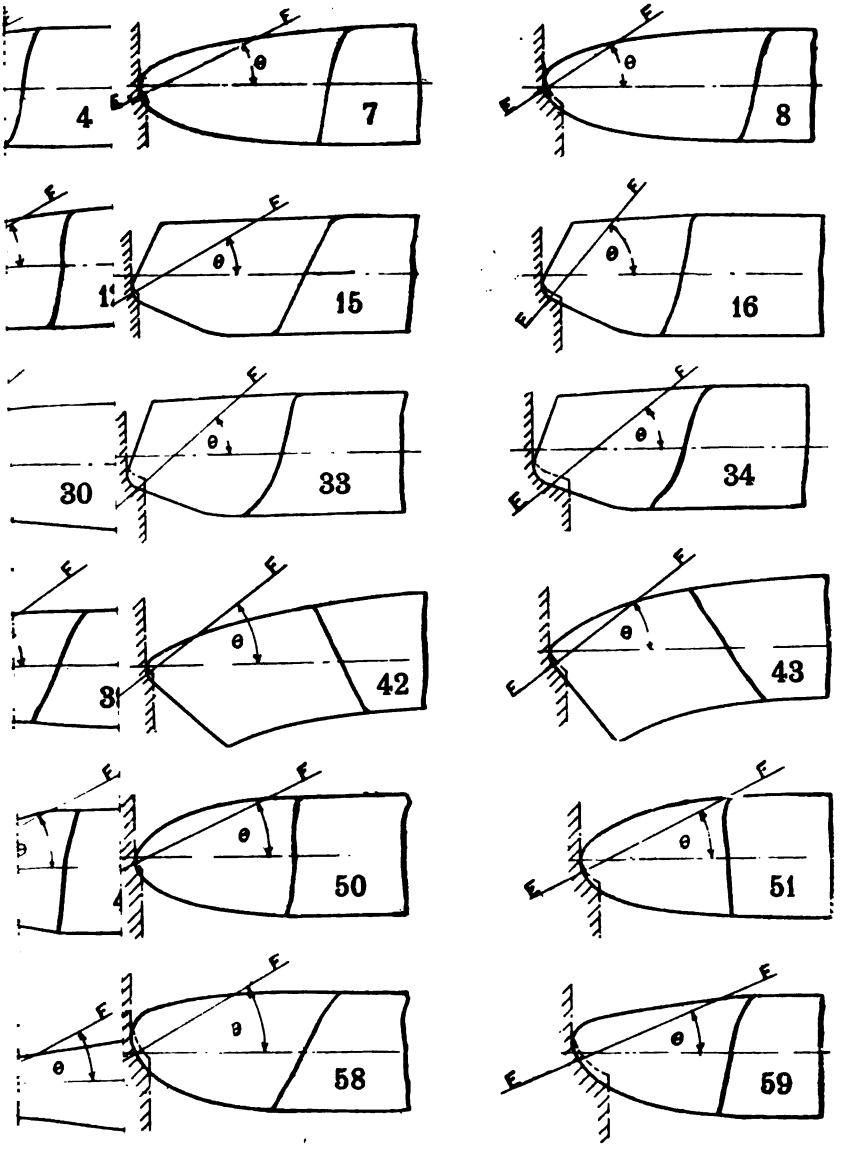

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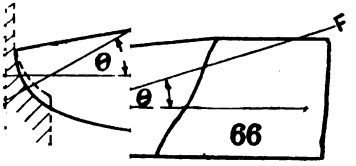
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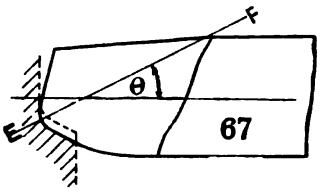
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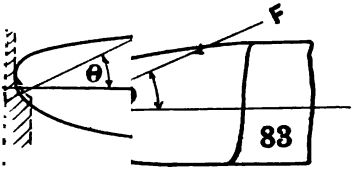
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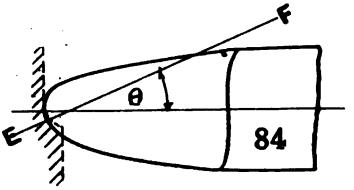
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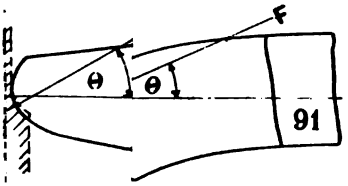
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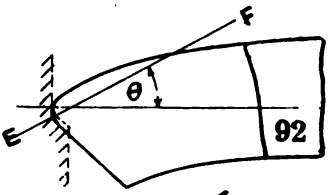
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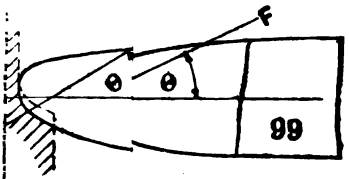
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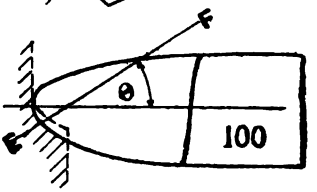
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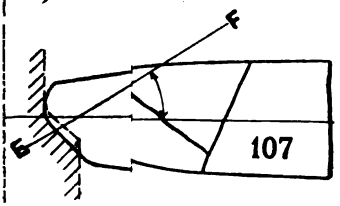
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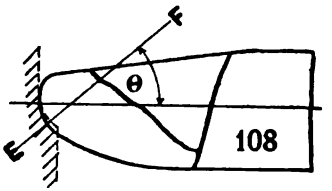
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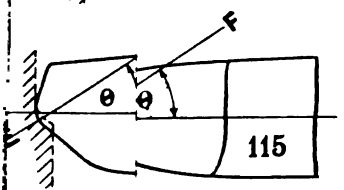
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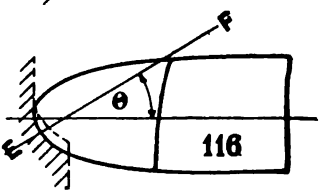
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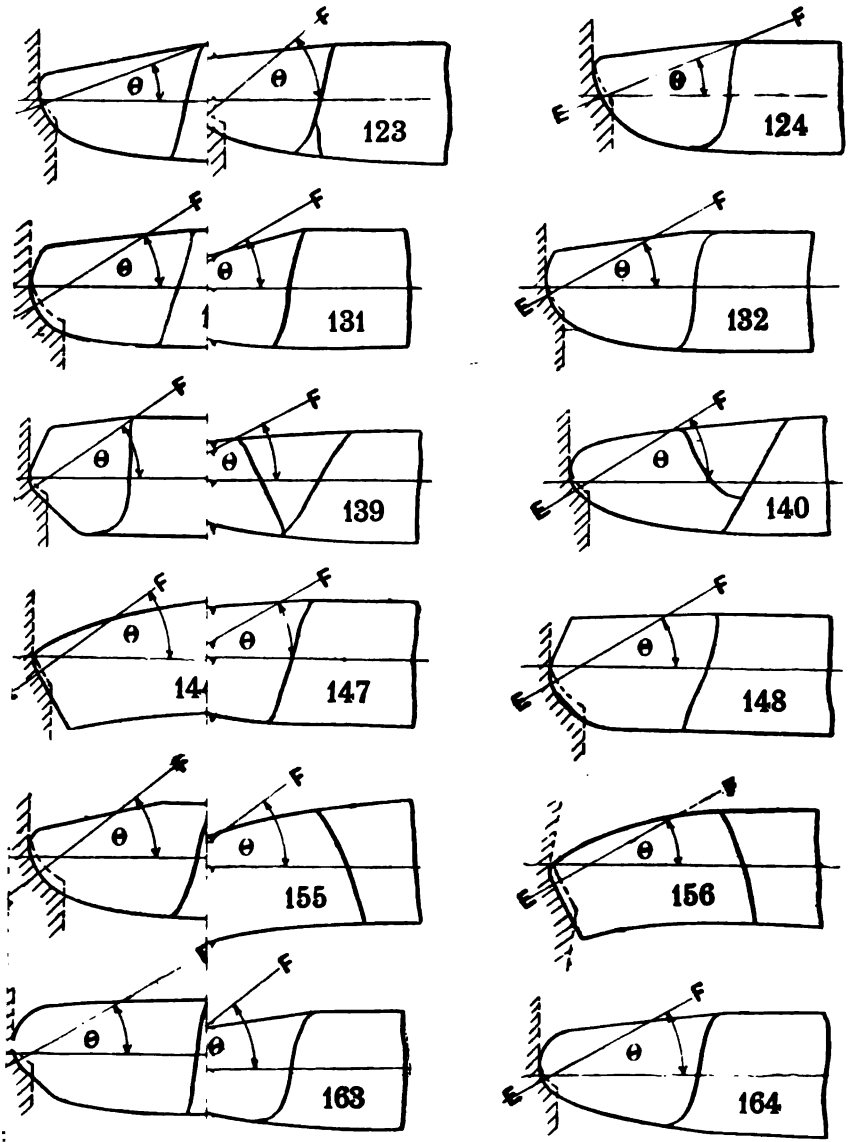

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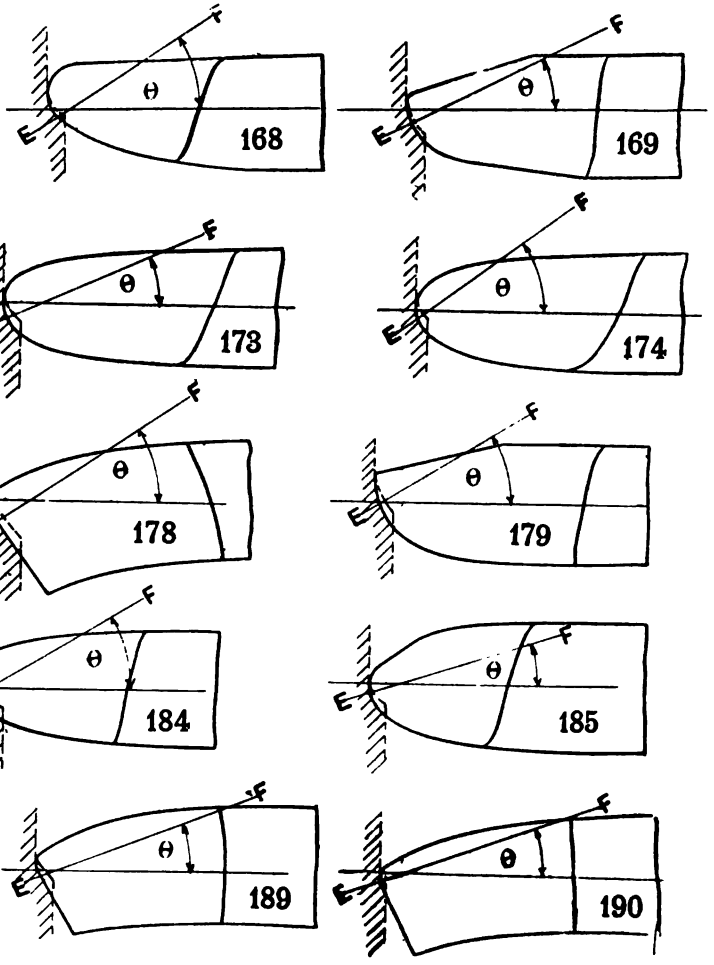
NG STEEL TOOLS.



SPEEDS OF MACHINE TOOLS.

WITH SPECIAL REFERENCE TO THE CORRECT PROPORTIONS OF PULLEYS AND GEARING.

READ SATURDAY, 14TH NOVEMBER, 1903,

BY

Mr. P. V. VERNON,

COVENTRY.

Most constructors have been inconvenienced by the want of some logical process for designing the cone pulleys and gearing for driving Machine Tools, so as to give an even graduation between the limits of highest and lowest speeds prescribed by the work to be done.

Examination of the speed and feed arrangements of machines by various makers leads to the conclusion that, in many cases, the only law which operates in their design is the law of trial and error, with the result that the best combination has not been discovered.

The difficulty of the problem when attacked in this way depends upon the degree of complication in the mechanism to be used, ranging from the simple cone pulley and one-speed countershaft to the elaborate combinations of pulleys and gearing used on some of the larger machine tools.

The author's attention was specially directed to this matter some years ago by points arising out of the design of the turret-lathe headstocks of Messrs. Alfred Herbert, Ltd., Coventry, and by the necessity which arose for providing each machine with a complete table of speeds and feeds. The construction of the tables at once rendered all defects and irregularities in the

speed ranges obvious, and pointed to the wisdom of adopting some systematic method of design, if the best results were to be secured and the criticism of customers avoided.

The object of this paper is then to indicate a method by which the calculations required may be organised, with the practical certainty of obtaining the desired sub-division for any given range and number of speeds.

The importance of the matter has perhaps hardly been realised to its full extent until recently, when the conditions of modern industry have rendered it necessary to obtain the greatest possible output from machinery of all kinds—this necessity being apparent in no branch of mechanics more than in the design of machine tools.

In presenting this paper to your Association, the author realises that the matter composing it may be not altogether new, and that other designers may have employed similar methods independently. If such be the case, he asks their indulgence, and will value highly any additional information which may be contributed.

In each of the examples given, a lathe headstock has been taken for purpose of illustration, and several arrangements of pulleys and gearing have been worked out to suit the varying conditions which may arise. The methods and arrangements employed will, however, be applicable with few alterations to the majority of machine tools intended to be used for general work.

In the case of machine tools for special purposes the speeds are sometimes arranged in irregular sequence to suit the peculiar conditions of the work, and it is to be understood therefore that the methods outlined below are not to be considered as applying to such special cases.

It will be noticed that in every example the required speeds are fixed before proportioning the means by which they are

obtained, thus rendering the means subservient to the end, rather than the end to the means.

Before considering any specific cases, it will be well to state broadly some of the conditions which are, as far as possible, to be fulfilled, as follows :—

1. The total range of speeds should be sufficient for all reasonable requirements.
2. The speeds should be sufficient in number.
3. The speed changes should be in geometrical progression through the whole range.
4. The smallest step of the cone-pulley (where used) should be as large as possible, so as to obtain an efficient belt-drive under all conditions.
5. The drop from one step of the cone-pulley to the next should not be great enough to render it difficult to move the belt.
6. The gear ratio should be as high as can conveniently be arranged, so as to obtain a relatively high belt-speed when on heavy work.

Having decided on the general design of the machine and the type of gearing to be used, it is first necessary to fix the number of speeds and their total range. These are matters which must be settled by the judgment of the designer from consideration of the requirements.

The next step is to plot out the speeds in a geometrical progression. Assuming the highest and lowest speeds and the number of means, the common ratio of the progression can be determined by the simple formula below :—

$$r = \left(\frac{b}{a}\right)^{\frac{1}{n+1}} \quad \text{or } r = \sqrt[n+1]{\frac{b}{a}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (a)$$

in which r = the common ratio.
a = the highest speed.
b = the lowest speed.
n = the number of means.

From this formula any of the intermediate speeds can be found by the equation—

$$s = a\, r^{p-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (b)$$

in which s = the required or p^{th} mean.

Although not difficult, the above calculations, which require the use of logarithms, may be replaced for drawing office use by a table of progressions, or "Ideal Speed Ranges," as shown by Plate I.

The figures in this table and throughout the paper have not been worked out to the ultimate decimal, but are quite accurate enough for practical purposes.

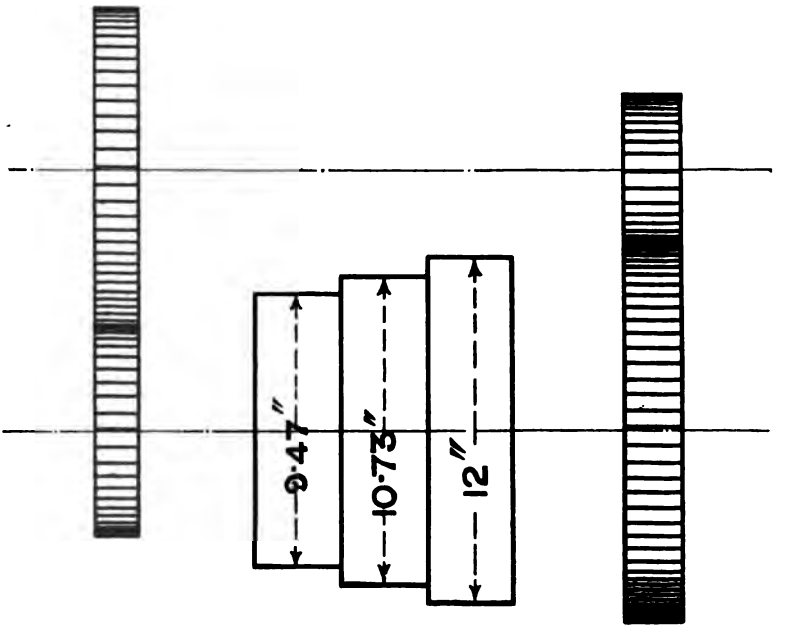


Fig. 2.
Countershaft speeds 221 and 109 turns per minute.
Gear ratio 4·11 to 1.

Example 1. (See Fig. 2.) For example No. 1 a case has been assumed in which it is required to find the correct proportions of gears and cone pulley for an ordinary double geared headstock to produce 12 speeds, varying from 280 down to 20 per minute. The cone pulley is to have three steps, the largest 12in. diameter, and will, of course, be driven from a two-speed countershaft. This example is representative of a type of headstock largely used on medium sized turret lathes.

Referring to the table (Plate I), it will be seen that the first number in each column is 1,000, so that a corresponding range of speeds in the table would have 12 speeds varying from 1,000 down to $\frac{1,000 \times 20}{280}$ or from 1,000 down to 71·4. Refer to table and look along horizontal line No. 12 for nearest figure to 71·4. This will be found to be 74·7 in the 21 % column, which is probably near enough for the purpose, and fixes the common ratio required at ·79, or 21 % of drop from speed to speed.

The required range will therefore have a percentage of drop from speed to speed of 21 % with 280 as a maximum. Plot out speeds as follows, either by calculation or slide rule: 280, 221, 174·7, 138, 109, 86·1, 68, 53·7, 42·4, 33·5, 20·9, 26·46.

It is next required to find the correct proportions of gears and cone pulley to produce the above speeds.

SINGLE SPEED OR DOUBLE GEAR →	SINGLE SPEED						DOUBLE GEAR.					
COUNTERSHAFT FAST OR SLOW →	FAST			SLOW			FAST			SLOW		
STEP OF CONE 1 2 3 →	1	2	3	1	2	3	1	2	3	1	2	3
SPEEDS →	280	221	174·7	138	109	86	68	53·7	42·4	33·5	26·46	20·9

Fig. 3.

The set of speeds as plotted above may now be arranged as in Fig. 8, which represents in a simple way the general arrangement or typical form for obtaining geometrical ranges for all combinations of gears, cone pulleys, and countershaft changes.

It will be seen that the arrangement consists of two main divisions of six speeds each, one division being entirely single speed and the other entirely double geared, each division giving half the range and without any overlapping.

Each main division consists of two sub-divisions of three speeds each, one for the fast and one for the slow countershaft speed, the sub-divisions being in the same order in each main division. Each sub-division consists of a group of three speeds, one for each step of the cone pulley, all in the same order and without overlapping.

Suppose, in the example, that the two cone pulleys, viz., the countershaft cone and that on the machine are identical, then the countershaft speeds will be 221 and 109 turns per minute.

Note. If the cone pulleys have an odd number of steps, the countershaft speed equals the speed of the driven cone with the belt on the middle step. If the number of steps is even the countershaft speed

$$= \text{quickest speed of cone} \times \sqrt{\frac{\text{slowest}}{\text{quickest}}} \text{ speed of cone} \ldots\ldots (c)$$

To avoid the determination of square roots and the use of logarithms, it is often permissible to ascertain the countershaft speeds by trial.

The largest diameter of the cone pulley is given as 12in. The smallest diameter then is equal to

$$\frac{\text{Largest diameter of cone} \times \text{Countershaft speed}}{\text{Quickest speed of cone}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (d)$$

$$= \frac{12 \times 221}{280} = 9{\cdot}47\text{in.}$$

The middle step = half the sum of the other two steps = 10·78in.

The proportions of the cone pulley have thus been arrived at irrespective of the ratio of the gearing, which remains to be fixed.

By inspection of the range of speeds above (Fig. 3), it will be seen that the ratio required is in the proportion of the first to the seventh speed, or as 280 : 68 = 4·11 to 1. The gears should be proportioned to give this ratio to the nearest tooth.

The required data are now complete, and the actual speeds may be laid out as follows:—

SINGLE SPEED OR DOUBLE GEARED →	SINGLE SPEED						DOUBLE GEAR 4·11 TO 1					
COUNTERSHAFT SPEED →	221			109			221			109		
STEP OF CONE (1 2 3) →	1	2	3	1	2	3	1	2	3	1	2	3
SPEEDS →	280	221	174·4	138	109	86	68	53·7	42·4	33·5	26·5	20·9

Fig. 4.

If the gears which can be used will not give exactly 4·11 to 1, the nearest approximation must be used.

Example 2. (See Fig. 5.) For this example a rather more elaborate type of headstock has been chosen, the conditions being to find the correct proportions of gears and cone pulley for a headstock with two ratios of double gears, the cone pulley to have three steps, the largest 18in. diameter, and to be driven from a two-speed countershaft. Eighteen speeds

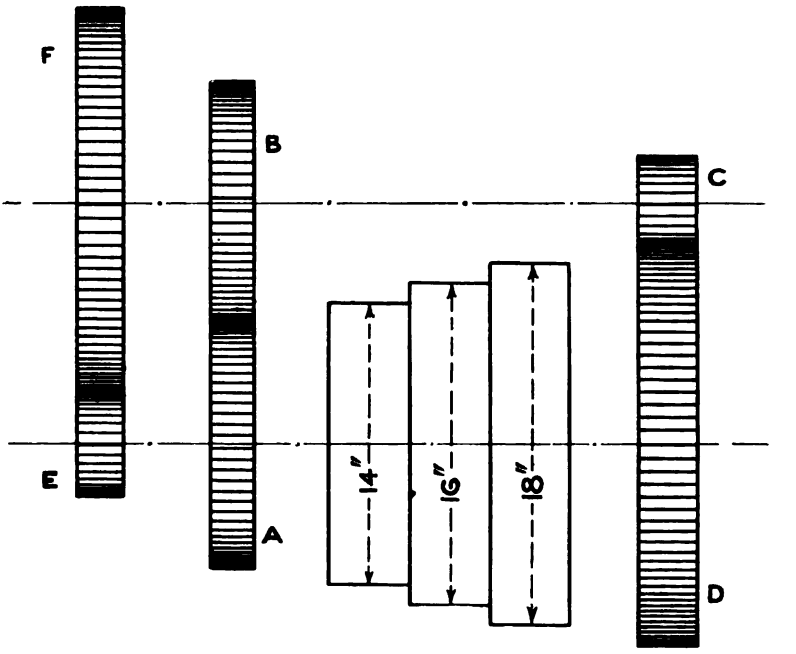


Fig. 5.

Countershaft speeds 234 and 111 turns per minute.

1st Group, 6 speeds, Single speed.

2nd Group, Do. $\frac{A}{B} \times \frac{C}{D} = 4{\cdot}44$ to 1.

3rd Group, Do. $\frac{E}{F} \times \frac{C}{D} = 19{\cdot}7$ to 1.

required, from $4\frac{1}{2}$ up to 300 turns per minute. This type of headstock is used on the heavy turret lathes made by the writer's firm, and is illustrated by Fig. 11, Plate II. In this case the speeds are to vary from 300 down to 4·5, and the corresponding range in the table, Plate I., should have 18 speeds, varying from 1,000 down to $\frac{1{,}000 \times 4{\cdot}5}{300} = 15$.

By looking along horizontal line No. 18, we find that 14·6 in the 22% column is the nearest figure to 15, and gives probably a near enough percentage for the purpose. If a greater degree

of accuracy be required, the percentage of drop can be slightly changed to suit, but as the adjacent columns only vary from each other by a difference of 1%, the table will be found to fulfil all practical requirements.

The required speed range will, then, have a drop from speed to speed of 22%, with 800 as a maximum.

Plot out the speeds in a similar manner to example No. 1 by calculation or slide rule.

	1st GROUP						2nd GROUP						3rd GROUP					
SINGLE SPEED OR LOW OR HIGH GEAR	SINGLE SPEED.						LOW GEAR.						HIGH GEAR.					
COUNTERSHAFT FAST OR SLOW	FAST			SLOW			FAST			SLOW			FAST			SLOW		
STEP OF CONE 1 2 3 →	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SPEEDS →	800	284	182 5	142 5	111	86 5	67 5	57 6	44 1	32	28	19 5	15 2	11 8	9 2	7 2	5 6	4 4

Fig. 6.

It should be noted that this table (Fig. 6) has exactly the same general form as in the first example, an extra division, however, being required for the extra gear ratio. The calculation is just as simple as in Example No. 1, although rather longer, and it will be shown later that the method is equally applicable to the most complicated arrangements of gearing.

In this case the countershaft speeds will be 284 and 111 per minute, as will be seen by inspection of Fig. 6, being equal to the second and fifth spindle speeds.

The largest diameter of cone pulley is given as 18in. The smallest diameter will therefore be $\frac{18 \times 284}{800} = 14{\cdot}4$, say 14in. The cone pulley will therefore have diameters of 14in., 16in., and 18in.

TO DETERMINE THE TWO GEAR RATIOS.

By inspection of the range of speeds above it will be seen that the ratio required for the low gear is in the proportion of the 1st to the 7th speed.

$$= 800 : 67{\cdot}5 = 4{\cdot}44 \text{ to } 1$$

The ratio for the high gear is in the proportion of the 1st to the 18th speed.

$$= 800 : 15{\cdot}2 = 19{\cdot}7 \text{ to } 1$$

This gear ratio is exactly the square of the first gear ratio. The three divisions of speeds will thus have gears forming a geometrical progression with a common ratio equal to the first gear ratio thus:—

Single speed.	1st Gear.	2nd Gear.
1	$1 \times 4{\cdot}44$	$1 \times 4{\cdot}44 \times 4{\cdot}44$
or 1	$4{\cdot}44$	$19{\cdot}7$

The above holds good for all arrangements planned by this method, no matter how many gear changes may be used.

The required data are now complete, and the speeds may be laid out as follows:—

	1ST GROUP.						2ND GROUP.						3RD GROUP.					
SINGLE SPEED OR LOW OR HIGH GEAR	SINGLE SPEED						LOW GEAR 4·44 TO 1						HIGH GEAR. 19·7 TO 1					
COUNTERSHAFT SPEED →	234.			III.			234.			III.			234.			III.		
STEP OF CONE 1 2 3 →	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SPEEDS →	300	234	182	142·7	111	86·5	67·7	52·7	40·9	32·1	25	19·4	15·2	11·8	9·2	7·2	5·6	4·36
% DROP →		22	22·2	21·6	22·2	22·2	21·6	22·1	22·5	21·5	22·1	22·4	21·6	22·5	22	21·7	22·2	22·5

Fig. 7.

In the lowest line in the above table the percentage of drop from speed to speed is given, and it will be observed that this is very close to the 22 % aimed at. If all the figures were worked out to sufficient places of decimals exactly 22 % would be obtained. It is not necessary, however, to overdo the calculations, or much time can be wasted without any corresponding gain. In many cases the gear ratios obtainable will introduce a slight error, which would more than extinguish the extra accuracy so obtained. In all practical work approximations are permissible, providing that the errors are small and are known. The gears should be proportioned to give the above speeds as nearly as the pitches will allow.

In fixing the pitches of the gears to obtain the required ratio, advantage may be taken of the fact that a small pitch may be made to transmit as much power as one which is larger by increasing the width of the gears, and the converse, of course, holds good also. In the days of cast gearing this could not be done on account of the necessity for using stock patterns, and also as there was no certainty that the teeth would take a bearing across their whole width, the strength being calculated on the assumption that the whole stress came on one corner of the tooth. By making some of the gears in steel, further possibilities of pitch variations are obtainable with cut gears, and thus it is possible in most cases to obtain almost exactly the gear ratio required.

Example 8. (See Fig. 8.) For this last example a design has been selected having a somewhat complex arrangement of gears with a view to showing the simplicity of the calculations involved and the satisfactory nature of the speed range obtained by the method under consideration, even for elaborate machines requiring many gear changes.

It is assumed that it is desired to find the correct proportions of gears and cone pulley for a headstock arranged to run single speed or through any of four separate ratios of gearing The cone pulley to have four steps, the largest diameter being 24in., and driven from a two speed countershaft giving 40 speeds varying from 1 up to 150 per minute. Fig. 8 shows the arrangement in diagrammatic form. The total ratio of speed range required = 150 to 1. The corresponding range on the table (Plate 1) will vary from 1,000 down to $\frac{1,000}{150} = 6{\cdot}66$.

By examining horizontal line 40 in the table we find that 6·7 in the 12 % column is the nearest figure to 6·66, and is near enough for the purpose.

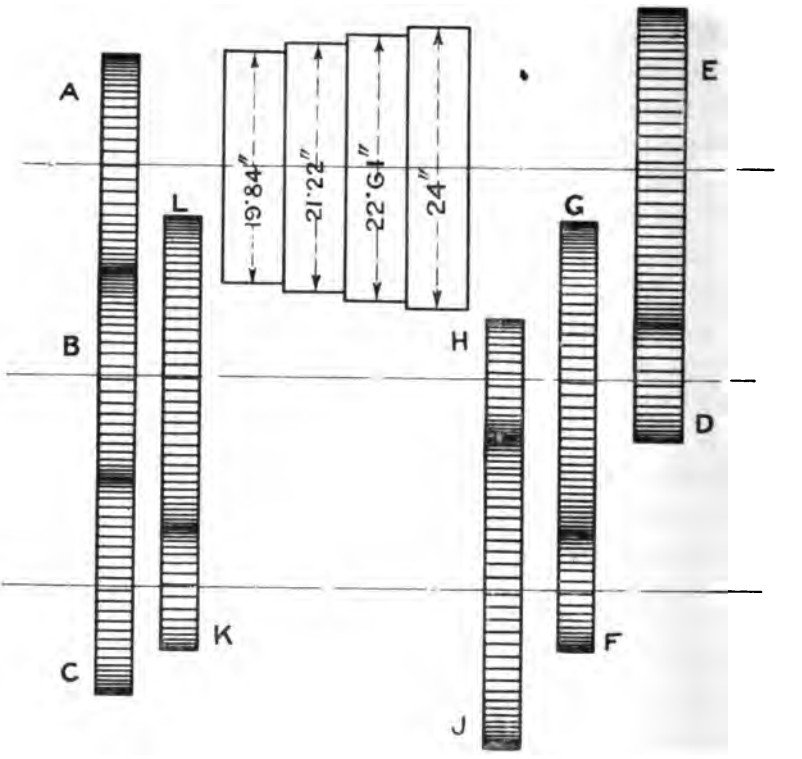


Fig. 8.

A B C are equal gears.

$\frac{D}{E}\ \frac{F}{G}\ \frac{H}{J}\ \frac{K}{L}$ are all equal ratios = 2·78 to 1.

Countershaft speeds 124 and 74·4 turns per minute.

1st Group, 8 speeds, Single Speed.

2nd Group, Do. $\frac{A}{B} \times \frac{D}{E} = 2{\cdot}78$ to 1.

3rd Group, Do. $\frac{A}{C} \times \frac{F}{G} \times \frac{D}{E} = 7{\cdot}74$ to 1.

4th Group, Do. $\frac{A}{B} \times \frac{H}{J} \times \frac{F}{G} \times \frac{D}{E} = 21{\cdot}55$ to 1.

5th Group, Do. $\frac{A}{C} \times \frac{K}{L} \times \frac{H}{J} \times \frac{F}{G} \times \frac{D}{E} = 60$ to 1.

The required speed range should then have a percentage of drop from speed to speed of 12 % with 150 as a maximum. Plot out speeds, following same method as in the previous examples (see Fig. 9).

	1ST GROUP.								2ND GROUP								3RD GROUP								4TH GROUP								5TH GROUP							
SINGLE SPEED OR 1ST, 2ND, 3RD OR 4TH GEAR.	SINGLE SPEED								1ST GEAR								2ND GEAR								3RD GEAR								4TH GEAR							
COUNTERSHAFT FAST OR SLOW	FAST				SLOW				FAST				SLOW				FAST				SLOW				FAST				SLOW				FAST				SLOW			
STEP OF CONE																																								
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
SPEEDS	150	132	116	102	90	79·1	69·6	61·3	53·9	47·4	41·7	36·7	32·3	28·4	25	22	19·34	17	15	13·2	11·6	10·2	8·98	7·9	6·95	6·11	5·38	4·73	4·16	3·66	3·22	2·83	2·5	2·19	1·92	1·69	1·49	1·3	1·15	1·01

Fig. 9.

	1ST GROUP								2ND GROUP								3RD GROUP								4TH GROUP								5TH GROUP.							
SINGLE SPEED OR 1ST, 2ND, 3RD OR 4TH GEAR	SINGLE SPEED.								1ST GEAR. 2·78 TO 1								2ND GEAR. 7·74 TO 1								3RD GEAR. 21·55 TO 1								4TH CEAR. 60 TO 1							
COUNTERSHAFT SPEED	124				74·4				124				74·4				124				74·4				124				74·4				124				74·4			
STEP OF CONE																																								
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
SPEEDS	150	132	116	102	90	79·2	69·6	61·2	53·9	47·4	41·7	36·7	32·3	28·4	25	22	19·37	17	15	13·17	11·6	10·2	9	7·9	6·96	6·12	5·38	4·75	4·17	3·67	3·23	2·83	2·5	2·2	1·96	1·7	1·5	1·3	1·16	1·02
% DROP		12	12	12	11·7	12	12	12	11·8	12	12	12	11·7	12	12	12	11·8	12	12	12	12	12	12	12	12	12	12	12	11·7	12	12	12	11·8	12	12	12	11·7	12	12	12

Fig. 10.

The cone pulley in this example has four steps, and the countershaft speeds must therefore be calculated, there being no middle step.

The fast countershaft speed, by formula (*c*) page 374.

$$= 150 \times \sqrt{\frac{102}{150}} = 123{\cdot}6, \text{ say } 124 \text{ turns per minute.}$$

By inspecting the range of speeds given in Fig. 9, it will be observed that the slow countershaft speed

$$= \frac{\text{Fast Countershaft speed}}{\text{Ratio of 1st and 5th speeds.}} =$$

$$124 \div \frac{150}{90} = 74{\cdot}4.$$

The largest diameter of the cone pulley is given as 24in.

The smallest diameter then by formula (*d*), page 375.

$$= \frac{\text{Largest diameter of cone} \times \text{Fast Countershaft speed}}{\text{Quickest speed of cone.}}$$

$$= \frac{24 \times 124}{150} = 19{\cdot}84.$$

The cone pulleys will therefore have steps 19·840in., 21·227in., 22·614in., and 24in. diameter, the diameters being in arithmetical progression with a common difference of 1·387in.

In cases where the drop in diameter between the steps of the cone is considerable, or where the drive is very short, it would be necessary to calculate the intermediate speeds separately, as equal differences in diameter do not give equal percentages of speed change. The calculation is made as follows :—

Let x = diameter of required step of driven cone.
,, y = ,, ,, ,, driving cone.
,, a = largest diameter of cone pulley.
,, b = smallest ,, ,, ,,
,, c = intermediate speed required.
,, d = speed of driving cone.

Then $x = \dfrac{a\,d + b\,d}{c + d}$ $y = a + b - x$.....*(e)*

In this, as in all other cone pulley calculations, a further correction in diameter must be made where the diameters vary greatly, or when the shafts are very close together, due to the variations of belt tension when an open belt is used.

When the speeds are calculated by the method here described, however, the variation in tension is so small that in the majority of cases no correction need be made.

TO DETERMINE THE GEAR RATIO IN EXAMPLE IV.

By inspection of Fig. 9 it will be seen that the ratios required for the four sets of gears are in the proportions of the first speed to the ninth, seventeenth, twenty-fifth, and thirty-third respectively. These ratios are in geometrical progression with a common ratio of 2·783 to 1, and work out at 2·78, 7·74, 21·55, and 60.

The required data are now complete, and the table of speeds may be finally laid out.

By comparing Fig. 10 with the skeleton diagram (Fig. 9), it will be seen that the desired range of speeds has been obtained within very small limits, and that the result is quite as accurate as is required. As the ratios of the various sets of gears are in geometrical progression, the first gear ratio only need actually be calculated, the second, third, and fourth ratios being the square, cube, and fourth power respectively of the first.

The ranges of speeds can be shown graphically by curves, but in this paper the tabular method has been preferred on account of its greater accuracy, and greater freedom from suspicion.

Having now fully described the system, and shown its applicability to many different arrangements of driving mechanism, it remains to compare it with the six conditions laid down at the beginning of the paper.

1. "The total range of speeds should be sufficient for all reasonable requirements."

   As the speeds are selected as the first step in the design, it is obvious that this condition can be fulfilled to any desired extent.

2. "The speeds should be sufficient in number."

   The system being applicable to any number of speeds fully satisfies this condition.

3. "The speed changes should be in geometrical progression."

   This requirement is completely attained.

4. "The smallest step of the cone should be as large as possible."

   As in every case the various steps of the cone pulley give successive speeds without skipping, it will be obvious that the cone pulley gives the least possible range of speeds, and therefore the smallest step has the largest possible relative diameter and the maximum efficiency.

5. "The drop from one step of the cone pulley to the next should not be great enough to render it difficult to move the belt."

   As the cone pulley has the least possible range of speeds, it must also have the least possible drop from speed to speed, and thus fully satisfies this condition.

6. "The gear ratio should be as high as possible."

   This object is also attained to its fullest extent owing to the fact that those speeds which are driven by belt alone are all at one end of the range, and give as little of the total range of speeds as possible, permitting, therefore, the employment of the greatest possible gear ratio.

Any speed range is obtained partly by cone pulley variation, partly by countershaft variation and partly by gear ratio. When the cone pulley and countershaft variations are at a minimum it is obvious that the gear ratio must be at its maximum for the given range.

Fig. 11, Plate II, shows a headstock designed upon the lines indicated above, and Fig. 12, Plate II, shows a headstock of the same height of centres, but of ordinary design. Comparison of the cone pulleys with the conditions laid down will easily demonstrate the superiority of the design shown by Fig. 11.

The method outlined above is applicable to the majority of machine tools intended for dealing with a wide range of work for which great variation of speed is required, and it will be observed that the effort of the machine opposed to the cutting tool is nearly in inverse proportion to the speed on a given diameter. This is as it should be for ordinary work, as the diameter of the work, the cutting speed and the feed react on each other in a regular manner. For instance, a finishing cut is taken at a higher cutting speed than a roughing cut but requires less peripheral turning effort, on account of the relative lightness of the cut. It is permissible then to dispense with some of the gearing when finishing.

When using the new quick cutting steels, however, the conditions are completely changed if it is required to take roughing and finishing cuts on the same machine. It is now usual practice to rough out with high speed steel, running the work fast, and to finish with tools made from ordinary steel running at a speed slower than that at which the roughing is done. This means that with an ordinary lathe the maximum gear ratio can only be used for the light finishing cuts, the heavy roughing cuts being taken with only a fraction of the power of the lathe. To remedy the inconsistency two courses appear to be open. The first is to keep separate lathes speeded

differently for roughing and finishing, a course which has much to recommend it, especially where repetition work is being done. The second course open is to have an extra set of quick countershaft speeds for roughing, so as to have the high gear ratio always available for the heaviest cuts. With a high gear ratio this necessitates very good gears if quick running is desired, but such gears can now be made without difficulty.

A partial solution of the high speed steel question may be to speed up our ordinary lathes and fit them with quiet running gears. It has frequently been stated that the high speed steels require more power in proportion to the quantity of metal removed than ordinary steels, but this statement is not by any means supported by the results of experiments which have come before the author's notice.

Since this paper was prepared the writer has had an opportunity of reading the Report of the Joint Committee of your Association and of the Manchester School of Technology on experiments carried out with high speed steels. The figures he has collected are in full accord with the above report, and he has therefore allowed them to stand without alteration. They may possibly be useful as independent and confirmatory evidence.

Figs. 13 and 14, pages 389 and 390, and Fig. 15, page 391, have been prepared from the results of some experiments which were made by Messrs. W. H. Allen, Son & Co., Ltd., Bedford, on roughing out forged Siemens-Martin steel armature spindles using high speed steel, and which they have kindly placed at the writer's disposal.

The tests were made on a large lathe electrically driven by a separate motor, and are most instructive. The three tables give figures showing the relation between cutting speeds and horse-power, cuts per inch and horse-power, and depth of cut and horse-power. Each table is divided into groups, lettered

A, B, C, etc. Each group represents a separate set of tests and bears no relation to other groups.

In the first table, Fig. 13, page 389, the diameter turned, depth of cut and feed are constant for each group, the cutting speed being varied and the horse-power recorded.

In the second table, Fig. 14, page 390, the diameters, cutting speeds, and depths of cut are constant for each group, the feed being varied and the horse-power recorded.

In the third table, Fig. 15, page 391, the cutting speeds and feeds are constant, the depth of cut being varied and the horse-power recorded.

The net results are as follows:—

1. The horse-power increases less rapidly than the cutting speed, or, in other words, less power is required in proportion to metal removed at a high than at a low speed.
2. A given horse-power absorbed removes more metal at a coarse than at a fine feed.
3. A given horse-power will remove more metal with a deep than with a light cut.

The figures thus show that a saving in power per unit of metal removed can be effected by increasing either feed, speed, or depth of cut. The saving in power, however, and consequent increase of output effected by increasing the speed, can often be obtained after the feed and depth of cut have reached the maximum that the machine and tool can withstand.

In order to show that these conclusions are supported by the results obtained by other observers, Fig. 16, page 391, has been appended. This table has been prepared from an article in *Engineering*, January 16th, 1903, dealing with Mr. Yarrow's experiments with "Speedicut" drills, and in the main supports

the results of the experiments of Messrs. W. H. Allen, Son & Co., Ltd., that the relative amount of power decreases as the cutting speed goes up.

Figs. 17 and 18, pages 392 and 393, give the results of the experiments of Messrs. W. H. Allen, Son & Co., Ltd., in full as supplied by them.

It appears, therefore, that the main objections to speeding up an ordinary machine tool to suit the new steels are only those due to the fact that the gearing may not be suitable for running quietly at high speeds, and that the bearings and other working parts may not be robust enough to resist the combination of speed, shock and bearing pressure, resulting from the taking of heavy cuts at a high speed. The power consumed per unit of metal removed should be less at a high speed, and a given machine should, therefore, be more economical in operation and quite satisfactory so far as regards its capacity to take heavy cuts, when speeded up, than before, assuming that the bearings are liberally designed, the pulleys well balanced, and the gearing properly cut.

In conclusion, the author wishes to state that he has not attempted to deal exhaustively with the question of machine-tool speeds. His investigations have been mainly directed towards satisfying his own needs as a designer, and will perhaps have only a passing interest to the general machine-tool user. The historic and inseparable connection of Manchester Engineers with the origin and development of machine tools is his excuse for bringing the matter forward.

APPENDIX.

Table showing the relation between cutting speed and horse-power for constant diameters, feeds and depths of cut using high speed steel tools.

Group.	Cutting Speed Ft. per min.	E.H.P.	$\frac{\text{E.H.P.}}{\text{Speed}}$	REMARKS
A	30·5	7·83	·257	Relative power decreases as speed increases
	43·5	9·6	·221	
	77·5	17·4	·224	
	112·5	19·12	·172	
B	77·5	7·83	·110	Relative power *increases* as speed increases
	112·5	15·7	·139	
C	31·2	5·23	·168	Relative power decreases as speed increases
	82	9·6	·117	
D	31·2	3·48	·111	Relative power decreases as speed increases
	82	7·83	·0955	
E	25	4·89	·195	Relative power decreases as speed increases
	37	5·76	·155	
	66·5	7	·105	It will be seen that four times the speed required less than twice the power
	77·5	7·35	·095	
	100	8·71	·087	

Fig. 13.

The results in Group B are opposed to all the other results, and are probably due to some unrecorded and exceptional cause.

The fourth column gives the power values of each test, and the figures represent the relative power consumptions per unit of metal removed.

Table showing the relation between horse-power and rate of feed for constant diameter, cutting speeds and depth of cut, using high speed steel tools.

Group	Cuts per inch	E. H. P.	E.H.P. by Cuts per in.	REMARKS
F	20 32	17·4 7·83	348 250	Power required increases faster than the feed
G	20 32	19·12 15·7	382·4 500	Power required increases more slowly than feed
H	20 32	5·23 3·48	104·6 113	Power required increases more slowly than feed
J	20 32	9·6 7·83	192 250	Power required increases more slowly than feed

Fig. 14.

Group F gives results opposed to those obtained by Groups G. H. & J. The mean result of all the experiments is however in the direction of greater economy at higher rates of feed.

The fourth column gives the power value of each test and the figures represent the relative power consumptions per unit of metal removed.

Table showing the relation between depth of cut and horse-power for constant cutting speed and rates of feed using high speed steel tools.

Group	Depth of Cut	E-H.P.	$\frac{\text{E.H.P.}}{\text{Depth}}$	REMARKS
K	·0625 ·25	32·5 50	520 200	In all cases relative power decreases as depth of cut increases.
L	·0937 ·1250	6·12 6·29	653 503	
M	·2812 ·3125	11·3 10·47	402 335	

Fig. 15.

The fourth column gives the power value of each test, and the figures represent the relative power consumptions per unit of metal removed.

Table showing the relation between cutting speed and horse-power for driving drills made of high speed steel. Diameter of drill, material drilled and feed constant: speed and horse-power varying.

(Figures converted from article in *Engineering*, January 16th, 1908, on Mr. Yarrow's experiments with Speedicut drills.)

Six Drills 1⅛in. diameter drilling Mild Steel Plates.

Turns per minute	Feed	E.H.P.	$\frac{\text{E. H. P.}}{\text{Speed}}$	REMARKS
50	200	12·66	·253	Relative power decreases as speed increases
76	200	15·76	·207	
96	200	16·6	·173	

Fig. 16.

Power required per unit of metal removed is about 20 % more at 76 than at 96, and about 46 % more at 50 than at 96.

The fourth column gives the power value of each test, and the figures represent the relative power consumptions per unit of metal removed.

POWER TEST OF TOOL STEEL

Made by Messrs. W. H. Allen, Son & Co. Ltd., Bedford.

Class of Steel:—"Capital" High-speed Steel.

Speed ft. per min.	Diameters in inches.	Feed Cuts per inch.	Depth of Cut in inches.	Weight of Metal removed in lbs. per hour.	Amperes indicated.	E.H.P.
30·5	3·6875	20	·375	110	45	7·83
43·5	3·6875	20	·375	165	55	9·6
77·3	3·6875	20	·375	292·5	100	17·4
77·3	3·6875	32	·375	183·5	55	7·83
112·5	3·6875	20	·375	440	110	19·12
112·5	3·6875	32	·375	274	90	15·7
The above show increase of power for increase of Speed.						
31·2	3·7187	20	·2187	65·5	30	5·23
31·2	3·7187	32	·2187	41·25	20	3·48
82	3·7187	20	·2187	175	55	9·6
82	3·7187	32	·2187	109	45	7·83

Showing increase of power for increase of Feed.

Fig. 17.

Material worked upon:—Forged Siemen's Martin Steel Armature Spindles.

Size of Tool:—$\frac{3}{4}$in. square. Approximate Voltage:—130 volts.

POWER TEST OF TOOL STEEL

Made by Messrs. W. H. Allen, Son & Co. Ltd., Bedford.

Class of Steel:—"Capital" High-speed Steel.

Speed ft. per min.	Diameters in inches.	Feed Cuts per inch.	Depth of Cut in inches.	Weight of Metal removed in lbs. per hour.	Amperes indicated	E.H.P.
69	4·8437	20	·0625	55·5	32·5	5·69
64	4·5312	20	·09375	57·5	35	6·12
65	4·625	20	·1250	70·5	36	6·29
69	4·875	20	·250	148·5	50	8·70
76	3·5625	20	·250	192·6	75	13
60	7·656	20	·09375	84·5	36·5	6·39
61·75	7·8437	20	·2812	155·4	65	11·30
62·50	7·9375	20	·3125	198·5	60	10·47
The above show increase of power for increased depth of cut.						
25	3·1875	20	·1250	32·3	28	4·89
37	3·1875	20	·1250	48·6	33	5·76
66·5	3·1875	20	·1250	86	40	7
77·5	3·1875	20	·1250	103·3	42	7·35
100	3·1875	20	·1250	129	50	8·71

Showing increased power for increased speeds.

Fig. 18.

Material worked upon:—Siemen's Martin Steel Armature Spindles.

Size of Tool:—$\frac{3}{4}$in. square. Approximate Voltage:—130.

DISCUSSION.

The PRESIDENT (Mr. E. G. Constantine) said there was plenty of interesting matter in the paper they had just heard for the consideration of both tool makers and tool users, and it was open for discussion. A number of visitors were present, and they would be glad to hear any remarks from those gentlemen.

Mr. W. H. PRETTY, of Bedford (visitor), said he had listened with great interest to the paper. The question of speeds was an important one; he had studied the subject in years gone by, and certainly thought the question of systematic speed variation was worthy of attention, both by the Manchester tool designers and others. Plate 1 was of interest, and if it afforded a stepping stone to more systematic design in the speeding of machine tools, he thought one object of the paper would be achieved. He would like to ask Mr. Vernon one question, with regard to the formulæ on Page 371. Was this obtained from a geometrical series? if so, he would suggest that the author might have given the actual geometrical series or progression used in obtaining this formula, so that those familiar with these mathematical series could interpret the actual part played by the symbols used. He also wished a few words had been said on the question of wider speed cones to enable wider belts to be used. A few years ago he was with Messrs. Allen, of Bedford, where he carried out a number of experiments with high speed tool steels, at the request of the directors, who had seen the well known tests of the Bethlehem Steel Company, both in the United States and at the Paris Exhibition. He found, in the first or primary attempts, that the cone speeds of most of the lathes were too narrow, thereby preventing the use of a wide belt, and it appeared to him, on reference to Fig. 11, Plate II.,

there might be more benefit derived by copying some of the older patterns in which the cone speeds allowed a wider belt to be used.

He would ask the author if he had thought of the possibility of representing the speed tables as given in Plate I. by a graphical curve or series of graphical curves. Such curves were of great use in drawing office work, and as Mr. Vernon only approximated to the values given by geometrical progression, he thought it might be of value here. The paper did not mention the possibility of arranging these gears by electrically driven tools, but he (Mr. Pretty) admitted that an efficient mode of motor control had yet to be found for the purpose.

The question of profiting by the use of high speed steels was referred to. It was very evident, generally speaking, that in the use of any machine or any serviceable article, they got the best return when running on "full load." This was a common engineering expression, worthy of more extended use, and if they wished to obtain the best results from high speed tools with high speed steels, they must run at full load, or as near this as possible.

He would say that the results given on Pages 892 and 898 of the paper were actual experimental facts. They might interpret them as they liked, and Mr. Vernon had taken considerable trouble to draw up tables from these results. He spoke of the results of Figures 17 and 18. They were as carefully determined as possible, and any doubtful tests were repeated before finally entering in the record book. Prior to the time when these trials were taken, other tests were made—in fact almost immediately after the Paris Exhibition—when the high speed steels were shown to such advantage. To his astonishment many of the tools were condemned as unsatisfactory by the workmen, and he could not find any reason for this in the ordinary way. He determined, therefore, to try and find a

means of identifying the steel after it had left the stores. The members knew the old fashioned way of cutting a piece of steel off, and how it passed from one hand to another. In several cases in which the steel tools were condemned he found it was not the fault of the steel, but of identification. So great was this trouble at the time that he wrote to Messrs. Seebohm and Dieckstahl, of Sheffield, asking if it was possible to mark the steel, say every 6 in. of the length, with a private mark, to identify the tool if anything went wrong. Every manufacturer of steel would understand how costly and troublesome this would be in the ordinary run of business, and he (Mr. Pretty) decided to seek some other means of identification. This led to his adopting the specific gravity test, and where firms buy large quantities of various steels he would ask them to have samples cut off, and get one of the apprentices to take them to the Technical School, and ascertain the various specific gravities and tabulate them. The specific gravity of the steel of any one particular *brand* and *maker* was fairly constant, and he was able to identify tools from a handful picked up at random by this method.

A useful tool for measuring the speed at which the work was moving—the surface speed—was the pocket rotameter (similar to the old wealemefna) for measuring the distance of lines on maps. That instrument was brought out to-day in the form of a rotameter as being quite new, but it was in fact really very old. For the same purpose he also had made a small instrument, which the members could make for themselves. It had the advantages of accuracy, durability, and handiness. He used an ordinary Starrett's speed counter, and put a wheel with a milled edge on the end of the spindle. This instrument was made in a manner which was described on the blackboard. The milled wheel 3·9095in. diameter was brought to the correct diameter by a milling tool and tested by rolling on a pad until

an exact distance of 12in. for one revolution of the wheel was obtained. By this method the instrument could be made very exact indeed; having checked it, there was nothing further to do but to drive the wheel on to the end of the spindle of the counter, the revolutions per minute on the speed counter giving a direct reading in feet per minute, the surface speed being read off at once. As the wheel is nearly 4in. diameter it gave considerable leverage on any rough surface or forging. It was a very useful tool for the workshop, and one not likely to get out of order.

Mr. Pretty referred to a method of measuring the cutting speed where flying cutters are used, the tool rotating and the work remaining stationary. He had drawn up a formula for this purpose by which the number of revolutions of the tool counted in a certain calculated number of seconds gave the surface or cutting speed. The general formulæ useful for all tools, whether with the work or tool rotating, was as follows:—

D = diam. in inches of the surface being turned or bored.

T = calculated time in seconds = 1·5708.D.

N = revolutions in time T.

F = cutting speed in feet per minute = 10.N.

Example:

D = 12·625.

T = 19·88 seconds (calculated time).

N = 8·5 (counted).

F = 10 × 8·5 equals 85ft. per minute.

The above was the general formula; it could easily be varied mentally by the person using it so as to make it more convenient for very large or very small work.

Mr. E. P. Hetherington (visitor) remarked that it had afforded him much pleasure to hear Mr. Vernon's paper read, as it was on the same lines that they (Messrs. Hetherington)

had been working for the last few years. There was only one point on which he would like Mr. Vernon's opinion, and that was, the true meaning of double gear. On Page 376 there was a diagram which, according to the sketch, had a pair of equal wheels, also a set of double gears. Messrs. Hetherington's description of that type of lathe was single speed, single gear, and double gear. The equal gears were *not* gears in his opinion. The word "gears", as he understood it, was an increase of ratio; they were gears, but had no gain of power. They were equal wheels. It was a matter of opinion as to whether the author preferred the word "double gear" where there was no increase of power.

In the changes from high speed, Mr. Vernon described the lathe being specially set apart for high speed, and the other portion of the work to be done on another type of lathe that ran at a slower speed. During the last few months his firm had been arranging lathes where they could get 100ft. cutting speed on all diameters, in proper progressive ratios, on the same lines as indicated in the paper.

High speed lathes were referred to. Messrs. Hetherington had been lately arranging their lathes with constant speed belt or for motor that they should have power to cut, say 100ft. per minute (which, although it was a matter of opinion, was quite high enough to attain to with the present tool steels), but if they were given a very hard piece of steel they could change on the lathes referred to the ratio of the gear by lever, etc., reducing the 100ft. cutting speed to 12½ for 25 or 50ft. per minute, as the turner might desire. This arrangement was much on the same lines as makers put in a slow reduction gear in drilling machines for tapping speeds.

Mr. F. W. Reed said he had not had an opportunity of examining the paper, but it struck him as being an exceedingly

good one, and very well thought out. There was no doubt that a great many tool designers, in the past, had been working to a very great extent to what might be termed a "trial and error" method.

Mr. Vernon had included the cone pulley and the changes of speed obtained thereby. It was not perhaps altogether what people could desire; on account of the drop from one speed to another, they could not get exactly the variation wished for, it must go up in steps; but now, with the addition of the speed variation countershafts which were being made, they could overcome these varying steps of the cone pulley, and this was a point which went further than Mr. Vernon's variation. The cone pulleys were now sometimes substituted by change gears, which could be changed from one speed to another with the moving of a lever instead of the belt. That was in advance of the step cone pulley, as the variation can be obtained quicker.

Mr. C. W. HUNT thanked Mr. Vernon for the valuable paper he had read, which contained information of considerable importance to a maker of lathes.

On looking at the paper, however, he was surprised to find the title "The Speed of Machine Tools," as so far as he could see the author had dealt more with the design of cones and gearing of lathe headstocks as practised at Messrs. Alfred Herbert's, Limited, Coventry, and he had not referred at all to numberless other machine tools such as planing, drilling, milling, slotting machines, &c,, &c., in all of which "speeds" and "feeds" was of the utmost importance, and he regretted some information thereon had not been given in a paper having such a title. Neither had the author given any particulars of the correct feed ratio for sliding and surfacing coinciding with such cones and gearing as had been referred to.

When he came to look at Fig. 12, Plate II., which he supposed represented a 12in. centre lathe headstock, he was somewhat surprised at the absurdity of the comparison between it and that of Fig. 2, Plate II., as such a comparison was unfair, even in a mere illustration; and whilst he did not know what other Coventry practice was regarding such headstocks as Fig. 12, Plate II., it certainly was not typical of ordinary modern lathe headstocks in the Manchester district, and of no other headstock he (Mr. Hunt) was acquainted with.

With regard to the design of cones. &c., generally, he might say most designers of lathe headstocks for ordinary sliding, surfacing, and screw cutting lathes were now agreed that the cone should have more steps than formerly, and for a 12in. centre headstock at least five steps were given with small differences of rise or diameter, always leaving the small step as large as possible so as to get an effective drive without belt slip.

With respect to gearing, these were now much finer in pitch than formerly, as it was found such gearing ran more smoothly and noiselessly, and the difference in diameters between the small gears and the large gears was correspondingly less, which gave a higher ratio of speed, yet still left the gearing amply strong enough for such duty as the lathe might be called upon to perform.

In some cases makers had dispensed with the use of cones on headstocks altogether, simply having a single speed for a wide belt, in which event a variable speed countershaft supplanted the older and well known cone type.

Mr. E. P. Hetherington observed that as far as the lathe headstocks were concerned, his firm put in four cones giving 24 ranges of speed to the spindle. The same remark applied to milling machines.

Mr. W. H. Cooke was of opinion that the paper was thoroughly practical, and one he would be pleased to place in the hands of any boy of his own if he was learning to design tools. If Mr. Vernon had been kind enough to give them some of the secrets of his firm—or of his own mind—to teach the tool designers how to design properly, he deserved every credit. He did not think the lower headstock on Plate II. an inaccurate sample. His experience went to show that the discarded headstocks were those with four or five cones with a 2in. belt surface, where the belt was always slipping off, and was altogether too narrow. What they required was a cone with a broad belt surface, where it could not easily slip off. Much can be done in modernising tools to meet the demands of the new high speed steels by taking out the narrow cones and substituting cones with fewer steps and broader surfaces.

Mr. Joseph Nasmith said that at the commencement of the tests of tool steel which had recently been reported upon, it was found necessary with the lathe supplied to them by Messrs. Armstrong Whitworth, in order to get the necessary power, to substitute fewer and wider steps on the cone pulley in the lathe for those which were in the lathe when it arrived. In that way they got the requisite power to enable them to develop the cut and traverse wanted. The three step headstocks might after all not be an obsolete thing to discard, but the precursor of something that had yet to come in consequence of the use of high speed tool steels.

Mr. S. H. Rowley pointed out that the fault of the headstock shown, and referred to by one or two of the members, was not the number of speeds, but the big drop between the speeds. Mr. Vernon had dealt with a lathe with a

straight bed. He would like to ask, if that lathe had a gap in it and it was desired to obtain a big range of speeds (suitable, say, for small brass work at one time and for cast iron at the full capacity of the gap at another, a not unusual experience when general work is dealt with), would he still advocate this geometrical progression, or would he make a distinct difference in the speeds of the countershaft or in the gears?

Mr. ALFRED SAXON said in the first place he had to compliment Mr. Vernon on his very admirable paper. He must also echo the sentiments of Mr. Cooke, that if all readers of papers were equally as candid as Mr. Vernon had been with his information, a greater amount of benefit would be reaped from the papers.

He did not know that morning that the experiments bearing on the paper were to be made, but the members who were present at the Technical School last week would remember that an invitation was extended to him to visit a neighbouring works (Armstrong Whitworth's), and that invitation he accepted. He had visited those works on Thursday last, and received a note from one of the officials of the firm to go again that Saturday morning. He had not the least idea what the purpose of the visit was for, but seeing that this two hours' test at Armstrong Whitworth's bore upon the statements contained in the paper, it must therefore be some excuse for his bringing it forward.

They were told on Page 886 of the paper that they had not anything like a definite percentage of saving given, and that saving, "these experiments seemed to furnish." There was a statement on Page 886 which ran as follows: "It has frequently been stated that the high speed steels require more power in proportion to the quantity of metal removed than ordinary steels, but this statement is not by any means supported by the results of experiments which have come before the author's notice." The

experiments carried out that morning showed that the high speed steels did not require more power in proportion. He would give them an idea how far. He had a number of figures, which he would furnish in the paper, giving the actual particulars of voltage, amperage, &c. The examples he would give as follows:—

First, with regard to cutting speeds and the difference in power. The piece of steel tested was a piece of fluid pressed steel, rather hard, ·6 carbon; ·66% manganese, $\frac{3}{16}$in. depth of cut, $\frac{1}{16}$in. feed, and speed of cutting 17ft. per minute, absorbed. when cutting, 5·16 HP. A test was taken later with a tool taking the same depth of cut and same traverse, but running at 42ft. per minute. The difference of gain in relative HP. was 19%. That showed with regard to the comparisons of high and low cutting speeds that there was a saving of 19% in relative power in high speeds.

Further experiments were taken with regard to depth of cut. The first was $\frac{3}{16}$in. depth of cut, $\frac{1}{16}$in. traverse, and compared with $\frac{1}{16}$in. traverse by $\frac{1}{8}$in. depth of cut, and the relative HP. saved was 28% in the deep cut over the shallow. A second example was taken of $\frac{1}{32}$in. traverse by $\frac{3}{16}$in. depth of cut, and $\frac{1}{32}$in. traverse by $\frac{1}{8}$in. depth of cut, the relative HP. saved was 25%, taking the two examples together the relative power saved was 26·5% in the deep cuts over the shallow.

A further test was taken with regard to traverse. The examples were: $\frac{1}{16}$in. traverse by $\frac{3}{16}$in. depth of cut, also $\frac{1}{32}$in. traverse by the same depth of cut, and this came out to a saving in relative power of 41% in the coarse traverse over the fine.

The greatest gain proved to be in the case of a coarse traverse in comparison to a fine traverse, this proved that a coarse traverse was more economical in power than either increased depth of cut or a high cutting speed, and that the

increased depth of cut came next in order. The increased speed of cutting, although considerably in advance of the slow, was not quite so pronounced in saving of power as the other two, viz., the coarse traverse and the increased depth of cut.

He (Mr. Saxon) also tested the two tools referred to in the discussion on the tool steel experiments and the power absorbed by those two tools taking $\frac{3}{16}$in. depth of cut each, and $\frac{1}{16}$in. traverse was practically the same as a single tool cutting $\frac{3}{8}$in. deep with the same traverse.

There was no time for "endurance trials" that morning. The above figures were fully borne out in the paper. He promised to send in tabulated form his remarks to the paper, which were now appended.

Fluid Steel. 6% Carbon. 66% Manganese.

Top Diam.		Feed	Depth of Cut.	Power Idle		Power Cutting		H.P. Cutting	Cutting Speed	Remarks.
				Amps	Volts	Amps	Volts			
No.	In.	in.	in.						ft. in.	
1	$12\frac{3}{4}$	$\frac{1}{16}$	$\frac{3}{16}$	10	220	17·5	220	5·16	17 0	1 Tool 1 sq. in.
2	,,	$\frac{1}{16}$	$\frac{3}{16}$	10	..	25	225	7·54	17 3	2 ,, ,,
3	,,	$\frac{1}{16}$	$\frac{3}{8}$	10	..	25	220	7·37	17 3	1 ,, ,,
4	,,	$\frac{1}{16}$	$\frac{3}{16}$	11	228	19	230	5·85	18 0	1 ,, ,,
5	,,	$\frac{1}{32}$	$\frac{3}{16}$	11	225	17	220	5·01	18 0	1 ,, ,,
6	,,	$\frac{1}{32}$	$\frac{3}{8}$	11	228	25	225	7·54	17 10	1 ,, ,,
7	,,	$\frac{1}{16}$	$\frac{3}{16}$	12	222	35	220	10·3	42 0	1 ,, ,,

Nos. 2 and 3 taken as example of one and two tools cutting.
,, 1 and 7 ,, ,, speed of cutting.
,, 1, 3, 5 and 6 taken as examples of depth of cut.
,, 4 and 5 taken as example of traverse.

Mr. S. N. Brayshaw thought the paper was a very valuable one, and the table particularly was well worth keeping for reference.

It was possible to design these (he had done it himself once) by worrying it out and getting somewhere near, but Mr. Vernon's calculations had been dealt with in a scientific manner. It was first of all the engineer's work to decide the extremes that he wants, and the number of steps, and then Mr. Vernon had dealt with the matter simply as a mathematician. It was an algebraical problem. Having solved that, it was a matter of common sense to set the results to the nearest they could get with their gears. It was then the engineer's problem to decide the widths of pulleys and gears and the general arrangements, and it seemed to him that the author had faced the whole problem. There had been no guessing or trying about it. He had started with a predetermined scheme, and that was the right way.

Mr. J. H. BEASTOW asked Mr. Vernon whether he referred to fine pitch gears (diametrical pitch gears) or coarse. Formerly it used to be rather coarse pitch gears in headstocks, and he would like to know if fine pitch gears were not preferable?

Mr. H. LIEBERT (Rochdale) asked if Mr. Vernon could give them some information regarding the speed of gears, and what he considered was the maximum speed to run the gears at?

Mr. T. SHAWCROSS said the paper was most instructive and very opportune, and he would like to give a few details in confirmation of the author's conclusions.

From an extended use of high speed steels, he had been long of the opinion that it was more economical to work at high rather than low speeds. He did not intend to say much on this point, as the experiments spoken of by Mr. Saxon clearly proved this; but he would like to speak of some heavy cuttings he had tried this week to confirm or disprove the statements made by the author regarding coarse feeds and deep cuts.

He had with him, and should be pleased for any gentleman present to examine same, two cuttings taken from a steel forging using tools made of "A. W." high speed steel, one of the cuttings being removed at a cutting speed of 50 feet per minute, $\frac{1}{4}$in. depth of cut, by a feed of four cuts per inch = 625lbs. of metal removed per hour, or 10·4lbs. per minute. During the time of cutting the nose of the tool was red hot, and although the tool successfully withstood the trial, it was distinct evidence of the punishment the tool was undergoing. The speed was then reduced to 30 feet per minute, the depth of cut being $\frac{3}{8}$in. and the feed also $\frac{3}{8}$in. = to removing 844lbs. of metal per hour, or 14lbs. per minute, the lathe apparently driving one cut as easily as the other. From the great difference in the weight of metal removed under the two conditions he thought it clearly showed where a large amount of metal had to be removed it was more economical to use a coarse feed and a deep cut than a light cut and a fine feed.

As an inspection of the cuttings will show, the high speed had much the better finish.

He then made a few trials drilling mild steel plates 2in. thick, the figures working out as follows:—

Drilling Mild Steel Plates 2in. thick with "A.W." High Speed Drills.

Diam. of Drill.	Revs. per minute.	Cutting speed ft. per minute.	Cuts per inch of feed.	Penetration per minute.	E.P.H. per inch of penetration.
1	84	22	100	·84	1·36
1	210	55	100	2·1	·98
1	375	98	100	3·75	·97
1	525	137	100	5·25	

The table shewed the economy of drilling at high speeds, for whereas at 84 revolutions per minute the net E.P.H. absorbed

equal 1·36 for each inch of depth drilled, whereas when the speed was increased to 875 revolutions per minute the nett E.P.H. absorbed for each inch of depth drilled fell 2·98, equal to a gain of nearly 28% in favour of the higher speed. When drilling at 525 revolutions per minute the amount of vibration set up precluded an accurate reading.

The PRESIDENT, in closing the discussion, heartily congratulated Mr. Vernon on his paper. He regarded it as one containing very valuable information, both to tool makers and tool users. It had the merit of being the result of very close thought, research, and industry, and he was personally not surprised at the eminence the firm had attained with which Mr. Vernon was connected, if they went into all their problems as Mr. Vernon had gone into that one. It reflected, to his mind, not only the greatest possible credit on himself, but also on his firm, who would employ anyone to tackle their problems in this manner.

There was undoubtedly no room for supposing that there was any better way of getting at the results of what a tool was likely to do than by first designing it on scientific lines, and then by actually testing the results obtainable.

The author had drawn attention to several important points. One was the great advantage of cut gears in modern tools. Not only in the accuracy of diameter, but in the greater speeds possible. The given range of speeds was an important point. These could be obtained in various ways, both by altering the speed of the cone, or by varying the gear, and the means which were now used for regulating the speed of countershafts.

Then there was the important subject of saving in power by high speed steels. This had been a revelation to many people, and there was no doubt this was correct, because it had been confirmed, not only by the experience of Mr. Vernon and Messrs.

Allen, of Bedford, but also by the results obtained by the Joint Committee in the recent Technical School tests.

Another point was the width of speed cones. Mr. Nasmith had already pointed out what they had found necessary in connection with the tests at the Technical School, and he (the President) was quite of the opinion of the speaker who stated that the illustration given in Figure 12 was largely representative of modern lathe practice in order to obtain the power necessary to deal with the high speed cutting steels taking heavy cuts.

One point mentioned by Mr. Pretty was important, viz., the specific gravity of the new tool steels. That was a new point to the President, and to probably a number of the members present. It seemed to be a very simple way of testing, if there was any doubt of the quality, as to whether they were using high speed cutting tools or the ordinary class of tool steel.

In conclusion he wished the members to show by the manner in which they received the resolution of thanks that was proposed, that they appreciated Mr. Vernon's kindness in coming from Coventry to give his paper. It contained a great deal of original information, and considerable benefit might be obtained from a careful study of it.

He had pleasure in proposing a hearty vote of thanks to Mr. Vernon for his paper.

Mr. P. V. VERNON, in reply said: He had hardly words to thank the members for the very kind way in which they had received the paper. He might say that the work of preparing it had been one of very great interest to him. Having, therefore, by dint of a certain amount of perseverance, attained results which had saved himself a great amount of labour, he felt it was his duty to communicate those results to his fellows.

In the first place, with regard to Mr. Pretty's remarks. He thanked him personally for the information supplied by the firm of Messrs. Allen. Respecting Mr. Pretty's criticism as to the formulæ used, and as to why he did not use the "well-known formulæ," the reason was that he (Mr. Vernon) did not know it. In dealing with the problem of geometrical ranges of speed, he had worked out the formulæ to suit the job, and although he had learned algebra in his school days, the recollection of many of the conventional letters and formulæ had now passed. In regard to Mr. Pretty's criticism as to the wideness or narrowness of the pulley used, these had been purposely omitted from the paper, as it did not come into the question of speed values at all. The system described could be used with any width of pulley, from the narrowest to the widest, the width of belt not affecting the method of dividing the speeds.

With reference to indicating the speeds by graphical curves, he had purposely omitted doing that. He had seen a great many of these curves. A diagram was obtained with a certain number of dots or lines. Assuming that the experimenter was honest, an honest curve might be expected, but unfortunately no experimenters were honest. They endeavoured to prove some point they had in their mind, and they drew some curve or line which suited their purpose, and which came somewhere near. He could prove, that certain curves published in connection with the design of certain machine tools were not correct. His own personal figures gave speeds which were actually to be obtained, and also showed up all errors which might exist.

With regard to electrically driven tools, he had purposely omitted those. He considered the variable speed motor might be used as a cloak to cover a great many faults in the design of the headstock. They could make the variation in the driving gear as much as they liked, it did not matter how great, and the

variation of the motor would cover it all. For that reason he had left it out.

At the same time, with a lathe designed upon the lines laid down in the paper, a variable speed motor could be used successfully. Also owing to the small variation in the cone pulley, by the system described the speed variation of the motor would be less than was generally found necessary in electrical driven tools.

He thanked Mr. Pretty for some of the tests he had described, especially the one for specific gravity, also the little apparatus he had made using a wheel on the speed recorder.

Referring to Mr. Hetherington's remarks, he was sorry to have to join issue with him. Mr. Hetherington stated that he had used exactly the same system as that described in the paper for many years. Now he (Mr. Vernon) came to that meeting with an analysis of the speeds of Messrs. Hetherington's lathe, as referred to in the *American Machinist* of October 10th, 1903. There it was stated that the speeds were in geometrical progression, and gave 100 feet per minute cutting speed on certain specified diameters. From these particulars he had calculated the actual spindle speeds required to produce those results. The figures actually representing the percentages of drop from speed to speed of Messrs. Hetherington's headstock, as per the advertisement in question, were as follows: 9·5, 9, 21½, 17½, 15½, 15½, 14, 18, 15½, 21, and 10. He left those figures to speak for themselves.

With regard to Mr. Hetherington's question as to the design of the headstock, Fig. 5, and the naming of the headstock as a "double-geared" headstock, he might say that those designs were not to scale, and they did not represent actual particulars of any headstock which he had in mind. In getting out the particulars, he was careful not to take any headstock that existed. He had taken general conditions only, and they could not be taken to represent any headstock that had ever been made.

Gear "A" was, as a matter of fact, usually greater than gear "B." It was very often found necessary to gear up from the pulley to the backshaft, and then down again to the spindle. There was no objection to doing this, provided they did not get too few teeth in the driven gears.

With regard to the name, he did not think it mattered what name was given; it was a question of what they got.

Mr. Hetherington's question as to the figure "1,000." He thought he (Mr. Hetherington) was under a slight misapprehension. This was only a method of calculation taken from the table on Plate 1, which was really a table of geometrical progressions. He could have started with 1, 100, or any other number, and the results would have been exactly the same.

He thanked Mr. Reed for his remarks. Mr. Reed mentioned the variable speed countershaft. It was quite true that the cone pulley did introduce steps into the curve, and although this was theoretically a small disadvantage, it was not really very great, providing they had sufficient steps. The ordinary workman was not able to say whether 21 feet or 21·1 feet per minute was the correct speed, and if he had a number of speeds which were fairly near to one another he could usually select one which would be quite as accurate as his judgment.

With reference to Mr. Hunt's remarks. Mr. Hunt stated that Mr. Vernon had only dealt with Messrs. Alfred Herbert's headstocks. In that Mr. Hunt was wrong; he had not dealt with a single headstock made by that firm.

In the last example he might state that he did not know of any existing headstock made by any toolmaker which was designed with that arrangement of gearing. The example was inserted to show how the principle could be applied to a complicated arrangement of driving gear, applicable to any ordinary machine tool.

As regards Mr. Hunt's criticism of the headstock shown in Figure 12 of Plate II. This particular illustration had come in for more hard words than any other portion of the paper. He (Mr. Vernon) would not divulge the name of the maker of that headstock, but it was *not* made in Coventry; it was made in "the north." The lathe was bought for the purpose of roughing out steel spindles, and it was bought from a firm who recommended this lathe especially for that work. The cone pulley shown was not the cone pulley supplied with the lathe. The pulley supplied with the lathe had five steps, and the belt was very narrow. The largest speed of the original pulley was smaller than the largest speed of the present one, and the same applied to all the other speeds. These facts would answer all the criticisms made on that particular headstock. As a matter of fact he might state that the lathe was now doing very well, kept on a certain class of work, and as the belt was kept on the one step of the cone pulley all the time it really did not matter what the other two steps were.

Mr. Nasmith's remarks as to the experiments which were made at the Manchester Technical School, and the necessity which arose for putting on a wider pulley on the spindle, also bore on the same point.

With regard to Mr. Rowley's remarks, and his question as to what he should do if he were to use a gap bed lathe, and had to provide a range of speeds suitable for large diameters, and also for small brass work. In the first place, he would not use a lathe of that kind if he could help it, and for small brass work he would use another lathe altogether. He would have one lathe for small work and one for large work. Assuming that he could not get the two lathes, then he might be persuaded to adopt different speed ranges. It should be noted that in the last paragraph on Page 870 this particular contingency was

provided for. Designers of boring mills would be quite familiar with that matter.

With regard to Mr. Saxon's remarks, he (Mr. Vernon) had also received an invitation to see the experiments at Messrs. Armstrong Whitworth's, but was unable to go. He thought if Mr. Saxon would contribute the figures he had mentioned, so that they might be printed with the paper, they would be valuable.

The matter of Mr. Saxon's two tools taking a certain depth of cut between them and the other single tool with exactly the same depth of cut, that also was a matter which ought to be recorded.

Replying to Mr. Beastow's enquiry as to fine pitch gears. Providing those fine gears were strong enough to do all the work of the headstock, he preferred the fine gears, as it was very much easier to get them to run smoothly and quietly, and to get an even turning motion throughout the whole revolution.

With regard to Mr. Liebert's enquiry as to whether he had any information as to the maximum speed at which the gears might be run, he had a certain amount of information, but he had made no generalisations yet. He knew certain gears which ran at certain speeds, but they were not collected in such a form that he could give any rules on the subject. He did not care to say much about it.

He thanked the members for their kind reception.

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2 Plates follow illustrating this Paper.

MACHINE TOOLS.

20%	21%	22%	23%	24%	25%	26%	27%	28%	29%	30%
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
800	790	780	770	760	750	740	730	720	710	700
640	624	608	593	578	562	548	533	518	504	490
512	493	474	456	439	421	405	389	373	358	343
410	389	370	351	333	316	300	284	269	254	240
328	308	289	271	253	237	222	207	193	180	168
262	243	225	208	193	178	163	151	139	128	118
210	192	176	160	146	133	121	110	100	91	82·3
168	152	137	123	111	100	89·1	81	72·2	64·5	57·6
134	120	107	95	84·5	75	66·1	59	52·4	45·8	40·3
107	94·6	83·3	73·2	64·2	56·2	48·9	43	37·4	32·5	28·2
86	74·7	65	56·4	48·8	42·2	36·2	31·3	26·9	23	19·8
68·7	59·1	50·7	43·4	37·1	31·6	26·8	22·8	19·4	16·3	13·8
55	46·6	39·5	33·4	28·2	23·7	19·8	16·6	13·9	11·6	9·7
44	36·9	30·8	25·7	21·4	17·8	14·6	12·15	10	8·2	6·8
35·2	28·1	24	19·8	16·3	13·3	10·8	8·87	7·23	5·8	4·7
28·16	23	18·7	15·2	12·4	10	8	6·47	5·21	4·14	3·32
22·5	16·2	14·6	11·7	9·4	7·5	5·9	4·7	3·75	2·94	2·32
18	14·3	11·4	9	7·14	5·6	4·4	3·44	2·7	2·08	1·63
14·9	11·3	8·9	6·9	5·42	4·2	3·25	2·51	1·94	1·48	1·14
11·5	8·9	6·94	5·4	4·12	3·2	2·4	1·53	1·39	1·05	
9·2	7·1	5·4	4·1	3·13	2·4	1·78	1·33	1		
7·37	5·6	4·22	3·2	2·38	1·8	1·31	·97			
5·9	4·4	3·29	2·46	1·81	1·3	·97				
4·72	3·39	2·56	1·89	1·37	1					
3·78	2·67	2	1·45	1·04						
3·02	2·1	1·56	1·11							
2·42	1·57	1·22								
1·93	1·32	·95								
1·55	·82									
1·25										
·99										

ED RANGES.

UNIV
OF
MICH

MACHINE TOOLS.

Fig. 11.

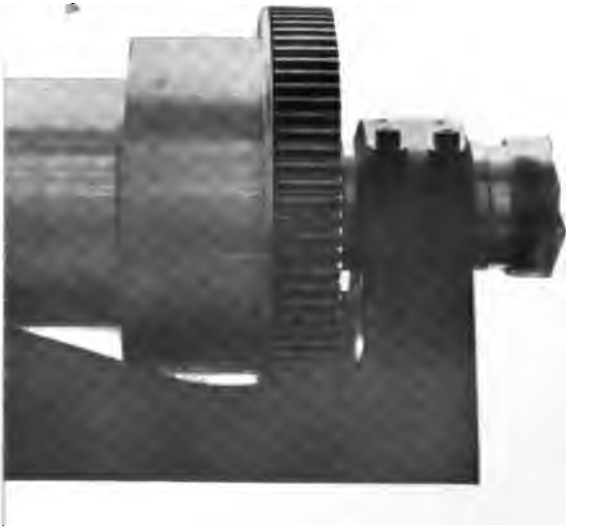


Fig. 12.

HOLY CROSS

CONDENSING PLANT FOR HIGH VACUUM WITH LIMITED WATER SUPPLY.

READ SATURDAY, 28TH NOVEMBER, 1903,

BY

Mr. W. H. ROY,

MANCHESTER.

The jet condenser is an invention we owe to the genius of James Watt, and until recent years no attempt was made to improve on the Watt condenser, which is in fact still almost universally used on mill engines in the textile industries. The surface condenser was invented to meet the requirements of over sea navigation, and land practice in these condensers has mainly followed marine lines.

During recent years the erection of large electricity supply stations, provided with engines running at relatively high speed, has necessitated condensing equipment with pumps independently driven instead of direct driven from crosshead as on mill engines. These independent plants have generally been of the surface condensing type, which is in the main superior to the standard parallel current condenser. Surface and jet condensers both require an amount of water for condensation equal, on an average, to 30 to 40 times the weight of steam condensed, and as a supply of water is not generally available from sea, river or canal, means have to be adopted to cool the water for continuous use. An open reservoir or lodge is generally used for this purpose in connection with the textile mills, but these lodges occupy large ground area and are relatively costly, and therefore are no use for large electric power stations. The difficulty of economically cooling water for

continuous use has been finally overcome by the introduction of cooling towers operating by natural draught. These towers occupy a ground area of about one square foot per HP as compared with about 40 square feet per HP required for a lodge, and the cost of a tower including foundations and concrete tank eight to nine feet deep is only 16/- per HP as compared with £2. 10s. to £4 per HP the average price for a lodge. (In this and other data given in the paper one HP means 20lbs. steam condensed per hour.)

Evaporative condensers, *i.e.*, a surface condenser with steam inside tubes and water trickling over outside, have been tried to a considerable extent to meet the difficulty of limited water supply for condensing. They are not suitable for high vacuum because it is difficult to keep tight the large number of joints exposed to the atmosphere, and for this and other reasons they are losing rather than gaining ground.

Assuming then that the cooling tower is the best method of dealing with the difficulty caused by limited water supply, we wish to discuss the best type of cooler and the theory and limits of condensing plant efficiency, especially in relation to high vacuum, such as 27 to 28 inches of mercury, required for plants working in conjunction with steam turbines.

High vacuums are not necessarily the most economical for all types of engine. In a paper contributed to the Proceedings of the Cleveland Institution of Engineers the author gave some data to show that for reciprocating engines, when cooling towers are utilised, to supply condensing water at a temperature of say 80° Fah., the point of maximum efficiency is reached at 26in. vacuum in counter current jet condensers, and 25in. vacuum in surface condensers.

Here we may digress to briefly consider the conditions of commercial efficiency for independent condensing sets, in other words, the question, does condensing always pay? Some

engineers identified with electrical supply, contend that in electric stations condensing often does not pay sufficiently well to justify its adoption.

A recent contributor to the Proceedings of the Institute of Mechanical Engineers gave some data to prove that in this country non-condensing electricity stations are superior in fuel economy and works' costs to condensing stations, but his data are vitiated by the fact that he has taken out his averages on a misleading basis. Figures are given both for Metropolitan and Provincial stations, for the financial year ending March, 1902, Omitting the Metropolitan stations, which for the most part labour under special disadvantages as regards condensing, we will consider the figures for Provincial stations only, being the averages of 116 stations for lighting only, and 82 stations for lighting and tramways. He obtains his average costs by multiplying the units sold in each station by fuel cot or works' cost, the sum of these results gives the total cost of generating all the electric supply sold by the stations under review, and this sum divided by total units sold gives the average price per unit. By this method of calculation a single large station with a low fuel cost obviously greatly reduces the average for the lot. Edinburgh, for instance, sells ten times as much electricity as any other non-condensing lighting station, and that on a very low fuel cost. With Edinburgh included the author's average for non-condensing stations is ·747d. fuel cost per unit, with Edinburgh excluded it becomes 1·043d. per unit sold. For condensing stations fuel cost per unit sold is 0·853d. With Edinburgh included the non-condensing stations show 12½% less fuel cost or fuel consumption than the condensing stations. With Edinburgh excluded from the non-condensing stations, the condensing stations show 18% less fuel cost or less fuel consumption than the non-condensing stations.

The average of all the fuel costs, irrespective of the relative number of units sold by each station, gives for 48 Provincial non-condensing stations (lighting only) 1·05d. per unit sold, and for 59 Provincial condensing stations (lighting only) ·942d. per unit sold, or a saving of 10% in fuel cost for the condensing as compared with the non-condensing stations. This is not a bad result considering that a great number of the stations are fitted with inefficient types of condenser, and pumps very wasteful in steam consumption, and in many cases the condenser is mainly used to help the generating plant over the peak of the load, rather than to economise steam consumption. Including 14 stations labelled "partly condensing," there is obtained a saving of 6% all over, which would indicate that in these partly condensing stations condensing is mainly utilised as stated above, to assist the generating plant in taking an overload.

Further, the real average cost for four non-condensing stations, and 28 condensing and partly condensing stations, providing power for lighting and tramways, shows ·757d. and ·650d. fuel cost per unit generated, or a saving of 14% in favour of condensing.

The results obtained as per my figures given above, put the question of relative economy on a different basis than that of the writer referred to, when he states "the tables show that in a lighting station non-condensing engines beat the condensing by 18% in fuel economy, taking the average over the whole country."

In concluding our observations on the above paper we may say that the writer quite correctly states that the reason why condensing plants in electricity stations often show poor results is that very little attention is given to this part of the station equipment. Cheapness in first cost is often the main object and thus pumps are put in most wasteful in steam consumption.

The exhaust pipe is generally too small diameter, and there is considerable drop in pressure between condenser and engine. On the other hand the author states that with a carefully designed condensing plant the economy in steam due to condensing on high-class triple expansion engines is 33% and the economy in coal 30%, and on an average the saving in fuel due to condensing will be 25% and with these figures we quite agree.

In any particular installation the question as to whether jet or surface condensing plant should be adopted, depends mainly on the quality, temperature and amount of water available for condensation. Four different conditions of water supply may be stated:—

1. Ample supply from fresh water, river or lake. Quality suitable for boiler feed. Quantity sufficient to effect condensation of steam without re-cooling.—Jet condenser the most suitable type of plant.

2. Ample supply from natural source, such as river or sea. Quality unsuitable for boiler feed. Quantity sufficient for condensation.—Surface, most suitable type of condenser. All marine engines in sea going steamers come under this head.

3. Supply suitable for boiler feed and limited in quantity. Relatively expensive to obtain and not sufficient for condensation. Water re-cooling plant must be used.

The majority of large steam engines for driving mills and electricity works come under this head. Jet condensers suitable.

4. Supply unsuitable for feed and limited in quantity. Water coolers require to be used. Softening or purifying apparatus required to make up loss of boiler feed due to

steam pipe and other losses. Collieries frequently come under this head. Surface condenser most suitable type.

Speaking broadly our main contention is that in all cases jet condensers should be adopted if the quality of water supply at all permits their use. Further, we will endeavour to prove that where a high vacuum of 27/28 inches is required, and only a limited supply of water is available, then the counter current jet condenser, combined with suitable pumps, will give the required vacuum at less initial cost, and with a less total expenditure of power than the surface condenser.

Substantially only two operations take place in condensing exhaust steam and obtaining a vacuum.

1. (*a*) Transmitting the latent heat of the steam to the condensing water. (*b*) Reducing the steam to water at or below the temperature equivalent to desired vacuum.

2. Extracting from condenser vessel the air present in same.

(*a*) As brought over by steam condensed in jet and surface condensers.

(*b*) Brought over by condensing water in jet condensers.

(*c*) Brought over by leakage in steam cylinders, exhaust pipes or condenser.

Of these two operations the first is the more important, and practically determines the second. In all first class plants for condensing steam and obtaining a high vacuum with limited water supply, there are four essential elements, viz :—water cooler, condenser, water pump, air pump, and the range of efficiency possible to the water cooler largely determines the capacity and design of the other three elements.

Cooling Towers.—We must therefore determine in the first instance the lowest temperature of injection water which can be economically obtained from a cooling tower, either with natural

or forced draught. A well designed natural draught cooling tower will reduce the temperature of condensing water to 80° Fah. under the average atmospheric conditions prevailing in this country, assuming that one square foot ground area is allowed for 70 to 75 gallons of water circulated per hour. This may be said to represent the highest efficiency the tower will obtain for any extended period of time. Under favourable atmospheric conditions the temperature will be lower, under less favourable conditions in the summer months the temperature will rise to 82° or 85° Fah.

Fan draught coolers are usually designed to give 80° Fah., and the extra cooling effect due to forced circulation of air is utilised to diminish the ground area occupied by cooling tower, or in other words increase the capacity. This type of tower has been largely used in America, and is there rated to deal with about 500/600 gallons per hour per square foot area.

Owing to the greater humidity of the British climate as compared with America or the Continent of Europe equal results cannot be obtained here, and therefore a fan draught cooler operating in this country may be taken as capable of dealing with 350 to 400 gallons of water per hour per square foot area occupied by tower. The power required to operate fans is at the rate of say 0·025 HP per HP of engines condensed.

Greatest stress is generally put on the temperature at which water leaves a cooling tower, but in fact the temperature at which the water enters the tower is quite as important a factor in determining the design and capacity of a plant to carry off a certain number of units of heat.

The cooling efficiency of any natural draught tower depends mainly on the following factors:—

A. The quantity of air passing through the tower in unit time.

B. The temperature and humidity of air at entrance to tower.

C. The temperature and humidity of air when last in contact with the water.

D. The area and design of surface over which the water flows.

E. Duration of contact between air and normal particle of water.

Of these factors B is beyond control, and C is perhaps the most important. C cannot be more and should not be less than temperature of water entering tower, and the air on leaving the water should be at point of saturation. A is partly controlled by temperature of water entering, which determines the temperature in upper part of tower and therefore the draught, and partly by constructive design—D and E largely control C.

The cooling of the water is effected, partly by raising the temperature of air passing through cooler as near as possible to temperature of entering water, and partly by evaporating part of the water. The higher the mean temperature of air passing through cooler the more water will be evaporated, and in practice the greater part of the cooling is effected by evaporation with the result that the loss of water from this cause varies from $2\frac{1}{2}$ to 4 per cent of water in circulation, or say 75% to 90% of steam condensed.

An examination of the accompanying diagram Fig. 1 will shew how important is the factor of evaporation in the total cooling effect. The ordinates measured from line A B to curve *Qd* represent to the scale shewn, the calories of heat contained by one kilo of air when fully saturated at respective temperatures marked on line A B. The parallel lines drawn through certain points on line A B and marked Q1 are drawn at an angle whose tangent is 0·24, that fraction being the specific

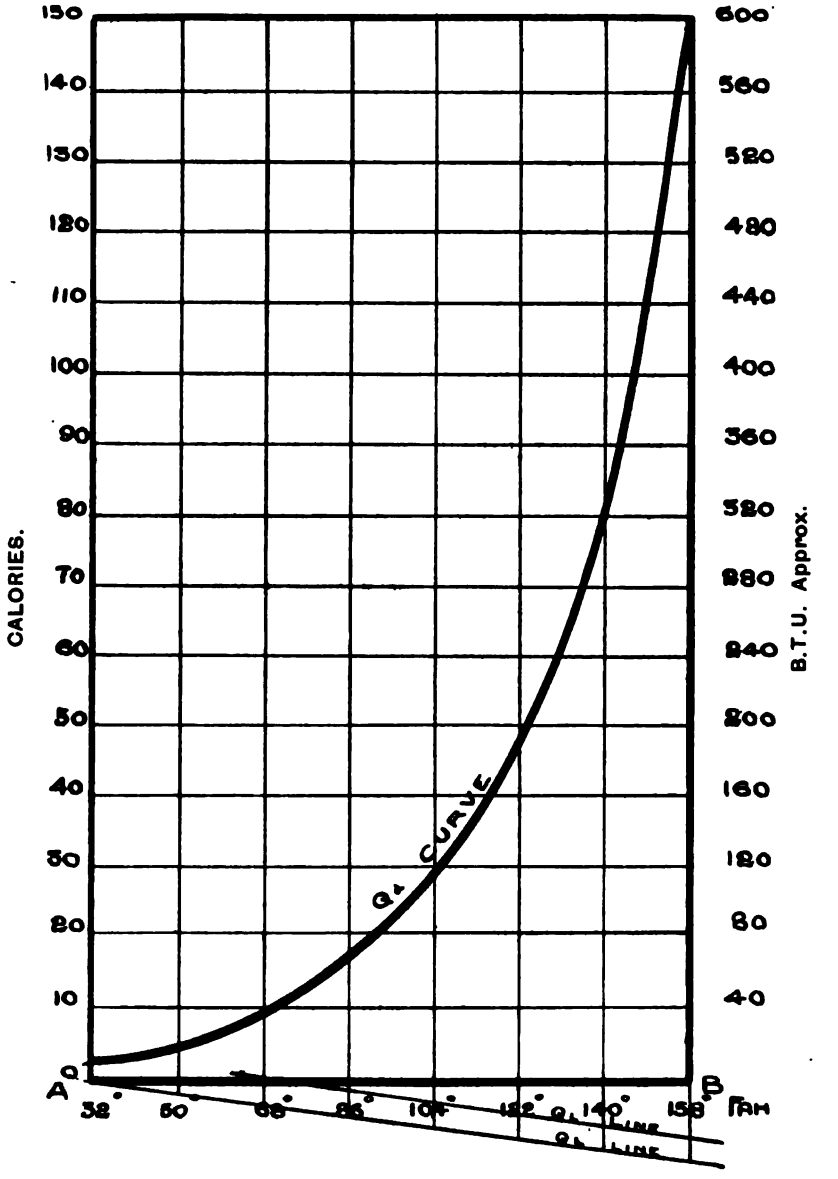

150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
CALORIES.
600
560
520
480
440
400
360
320
280
240
200
160
120
80
40
B.T.U. Approx.
Q_4 CURVE
A
B
32°
50°
68°
86°
104°
122°
Q_1 140° LINE
158°
FAH
Q_2 LINE

Fig. 1.

heat of air at constant pressure. To determine the greatest amount of heat in calories which will be taken up by one kilo of air entering a cooling tower at 68° Fah. and leaving at say 124° Fah., we measure the ordinate enclosed between Q1 line 68° Fah. and line A B which gives calories required to raise one kilo. air from temperature of 68° Fah. to 124° Fah., and the ordinate between A B and Q*d* curve gives the calories required to evaporate sufficient water to fully saturate 1 kilo of air at 124° Fah. The total calories therefore taken up by one kilo of air entering cooler at 68° Fah. and leaving at 124° Fah. fully saturated is say Q = Q1 + Qd. It will be noticed that this ordinate is more than 50% greater when air leaves at 124° Fah. than when it leaves at 104° Fah.

When a given weight of steam has to be condensed, a certain definite amount of heat has to be abstracted to reduce steam to water at a temperature which will permit a certain vacuum to be obtained. Assume 1,020 B.T.U. have to be extracted, and a vacuum obtained equal to 27in. of mercury, the corresponding temperature being 114° Fah., then if we use a counter current jet condenser we can heat the water up until it leaves the condenser practically at 114° Fah., the temperature of the steam, and if water is cooled down to 80° Fah. (being a reduction of 34° Fah.), 30lbs. of water will require to be kept in circulation for every 1,020 B.T.U. extracted, or approximately every pound of steam condensed. On the other hand if we use a surface condenser, then, owing to the imperfect transmission of heat through tubes, the water may leave the condenser as much as 16/18° Fah. less in temperature than steam, or say at 97° Fah., and if cooled down to 80° Fah. (being a reduction of 17° Fah.) 60lbs. of water will require to be kept in circulation for every 1,020 B.T.U. extracted. It is therefore found in practice that on an average the surface condenser requires nearly twice as much water to be kept in circulation as

is required for a counter current jet condenser. Also owing to the relatively low temperature at which the water enters the cooler, less heat is extracted by every pound of air passing through cooler, or in other words, for a given cooling effect in units of heat more air requires to pass through, which practically means the use of a larger cooler.

The temperature at which the water must leave the condenser to give the required vacuum, and the temperature and humidity of the atmosphere are therefore the two factors which mainly determine the capacity of any given cooler. In a surface condenser as referred to above we might try and reduce the water to 70° F. when leaving the cooler, and thereby diminish the amount of water in circulation, but this 10° nearer approach to atmospheric temperature means a large increase in cooling surface, and possibly in height of lift of water. Every degree by which the temperature of water leaving cooler approaches atmospheric temperature is obtained with increasing difficulty, whereas every degree by which we can allow the top temperature to rise enhances the efficiency of the cooler.

In this climate to continuously reduce the temperature of condensing water from 100° Fah. to 70° or 75° Fah. on anything like reasonable ground space, it is practically necessary to resort to fan draught to circulate the large quantity of air required. The ordinary fan cooler reducing water from 120° Fah. to 80° Fah. requires at least 2¼% to 2½% of HP condensed to drive fans, and to reduce from 100° to 70° will require a much larger cooler, and 75% more power. Most engineers when they look carefully into the question will object to wasting 4% to 4½% of the power developed by the main engines, merely for the satisfaction of using a standard, relatively expensive surface condenser.

Condensers.—These may be divided into four types :—

A. Counter current surface condensers.

B. Counter current jet condensers.

C. Parallel current jet condensers.

D. Parallel current surface condensers.

Practically all surface condensers are counter current, the parallel current being only used in a few exceptional cases. Until recently the majority of jet condensers were parallel current, but the counter current jet is now being generally adopted.

In a counter current condenser, either jet or surface, the steam and injection water enter at opposite ends of the condenser vessel, and travel in opposite directions, the condensing water leaving at the hottest part of condenser where the steam enters. In a parallel current jet condenser the steam and water enter at the same end, and the condensed steam and condensing water leave the condenser together at the opposite end.

For high vacuum and limited water supply the most efficient type of condenser is that which most nearly fulfils four conditions :—

A. To condense the exhaust steam with the least relative amount of water, and least expenditure of power in circulating same.

B. To deliver the condensed steam to the hot well at the highest possible temperature, and thus conserve for boiler feed as much as possible of the heat contained in the exhaust steam.

C. To deliver the condensing water to the Cooling Tower at the highest temperature possible and thus, as we have shewn, enhance the efficiency of the cooling apparatus.

D. To enable the air pump to take the air away at the coolest part of the Condenser where it occupies least volume, and thus reduce capacity of air pumps and power required for same to a minimum.

The counter current jet condenser is the only type which completely meets the above conditions. The counter current surface condenser is designed on right lines, but as the heat has to be transmitted through metal surfaces its efficiency is limited on all points except D. The parallel current jet condenser in its ordinary form, combined with a wet air pump, is deficient on all four points and is a radically unscientific design.

The parallel jet condenser of the barometric type as sometimes used partly meets conditions A and D and is defective on B and C.

Figs. 2 and 3, Pages 430 and 431, illustrate standard types of vertical counter current and horizontal counter current jet condensers.

Fig. 5, Page 435, is a standard parallel current condenser to work with wet air pump. Fig. 4, Page 433, is a parallel jet condenser of the barometric type. This design is, I believe, of American origin, but several plants have recently been erected at electricity works in this country in which a similar condenser has been used.

In all condensers, jet or surface, counter current or parallel current there is a certain difference in absolute pressure and in temperature at different points in the condenser, otherwise there could be no flow or current of steam through condenser. The absolute pressure in engine cylinder must also be more or less in excess of abolute pressure in condenser to produce the flow of steam through exhaust pipes, these pipes being made as large as possible in order to reduce frictional resistance.

In a counter current jet condenser the condensing water and condensed steam will leave at a temperature almost the same

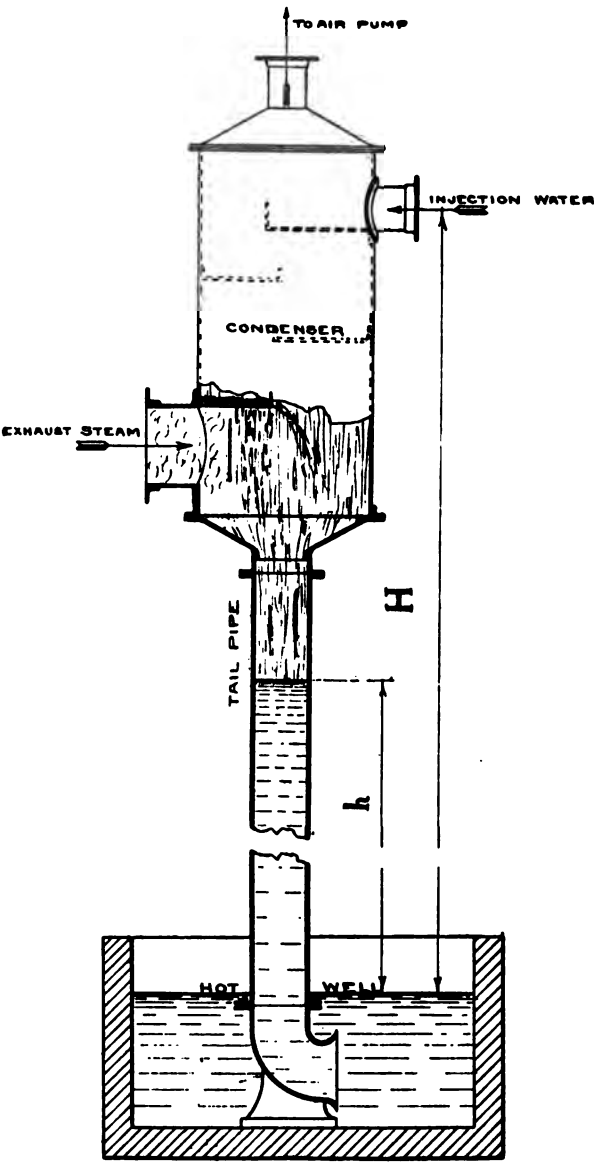

TO AIR PUMP
INJECTION WATER
CONDENSER
EXHAUST STEAM
TAIL PIPE
H
h
HOT WELL

Fig. 2.

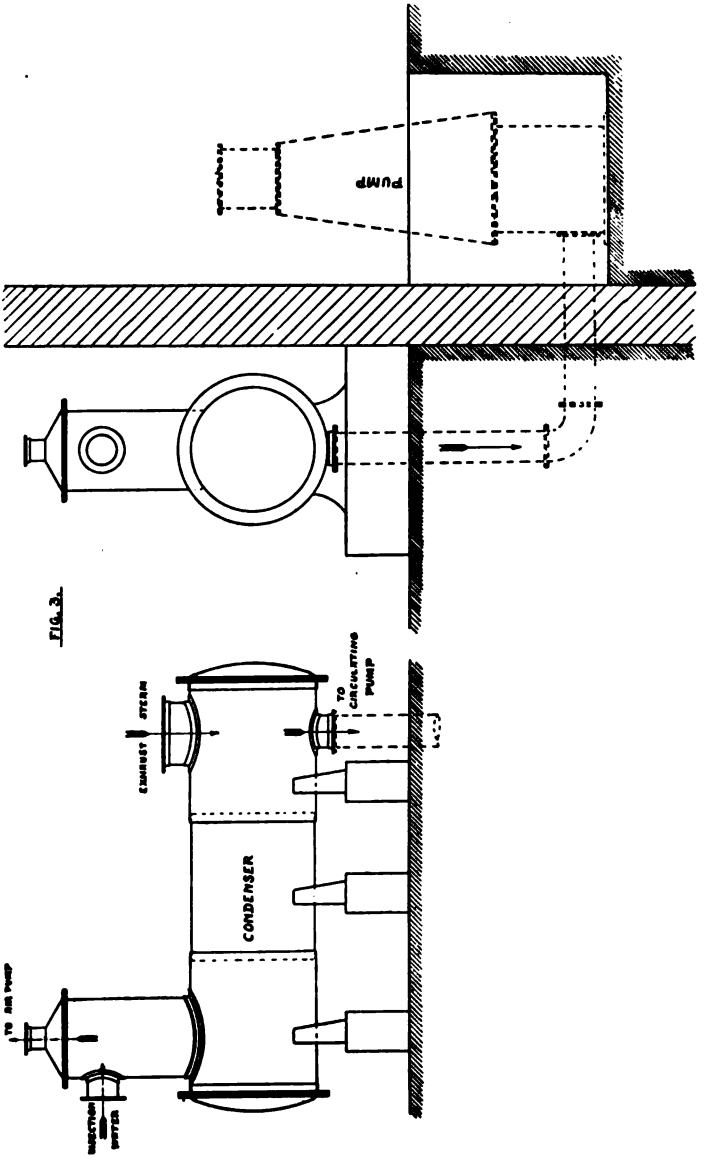

PUMP
EXHAUST STEAM
TO CIRCULATING PUMP
CONDENSER
TO AIR PUMP
INJECTION WATER

Fig. 3.

as entering steam, and thus comply with the conditions B and C., and as the water in circulation is heated to the highest possible temperature a minimum quantity is required, which meets conditions A, and if the counter current condenser is of Barometric type the least power as well as least water will be required. In the counter current condensers, shewn in Figs. 2 and 3, the steam travels in an opposite direction to the water, and the water is sprayed inside condenser by perforated trays or other devices, and ultimately the air is sucked off by air pump from coldest part of condenser, as required by condition D.

In a counter current surface condenser the steam and water do not come into contact, and the temperature of latter as it leaves the condenser will always be less than temperature of steam. The difference depends on relative area of tube surface, and is on an average 16° to 18° Fah. For the same vacuum and same temperature injection water the amount of condensing water is always considerably greater for counter current surface condenser than for counter current jet condenser, and also more power is expended in circulating.

In a counter current surface condenser the temperature of water in hot well is always less than in counter current jet for same vacuum, and thus colder feed is supplied. This is due to the fact that in the counter current jet the condensed steam is mixed with the condensing water, and being last in contact with entering steam is discharged at the highest possible temperature. In a counter current surface the condensed steam is last in contact with entering water, and leaves condenser at a temperature more or less approaching temperature of injection. The surface condenser is therefore less efficient than jet on points 1, 2 and 3.

The air pump requires to be larger for a counter current jet than for a counter current surface condenser, the difference being due to the extra air brought over by injection water. The

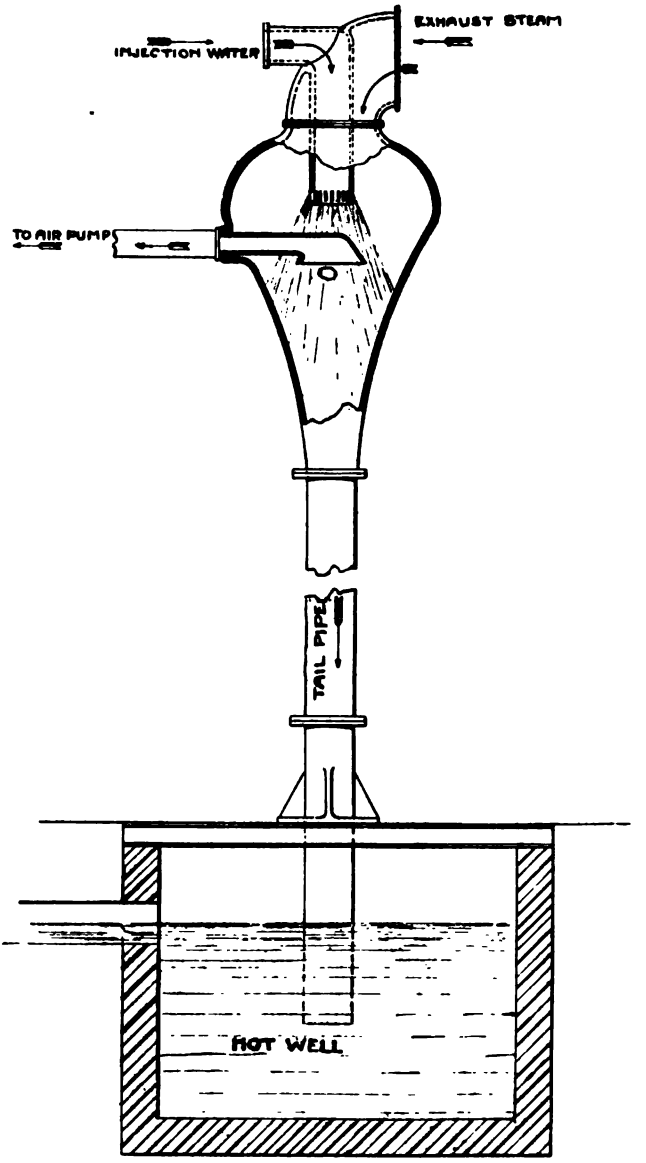

EXHAUST STEAM
INJECTION WATER
TO AIR PUMP
TAIL PIPE
HOT WELL

Fig. 4.

leakage factor is so large an element in air pump capacity that the difference between air pumps for the respective types of plant is not so large as might be expected.

The parallel current jet condenser shewn in Fig. 4 is more efficient than the ordinary parallel current condenser shown in Fig. 5, but less efficient than the counter current jet. It is not possible in this type of condenser to heat the ejection water up to the temperature of entering steam, the difference being about 8/10° in Fig. 4 design, and 12° to 14° in Fig. 5 design.

These differences are not so important with moderate vacuums and low temperature of injection, but with high vacuum and injection water at 80° Fah. a difference of even 5° in temperature of water leaving condenser means considerable increase in quantity of water in circulation.

The temperature of water available for boiler feed in Fig. 4 and Fig. 5 Condensers is also lower than temperature in Figs. 2 and 3 condenser by the difference of 8/10° or 12/14° as stated above.

The relative efficiency of air pumps for Fig. 2 and Fig. 5 type will be discussed later on.

Water Pumps. Fig. 7, Page 488, shows the relative quantity of water which requires to be kept in circulation for counter current jet condensers and counter current surface condensers respectively at the specified vacuums. The curves in both cases have been taken on a basis of maximum efficiency as regards transmission of heat from steam to water in the respective condensers: allowances would have to be made in practice depending on the design of condenser and conditions under which it operates.

The different types of pumps generally utilized to circulate condensing water are :—

1. Reciprocating piston or plunger pump, double-acting, horizontal or vertical.

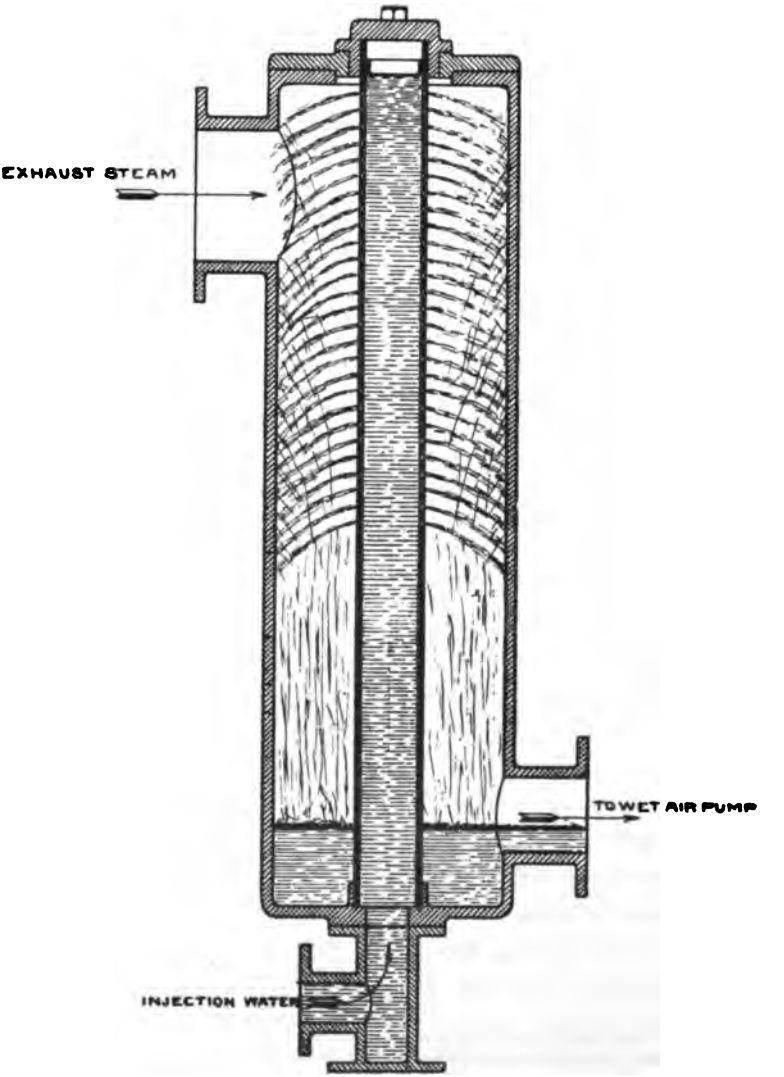


Fig. 5.

2. Centrifugal pump, direct connected to steam engine or electric motor, or belt driven.

3. Rotary positive action-pumps, driven by direct connection or by belt from steam engine.

When parallel current condensers of Fig. 5 type are adopted a "wet" air pump is generally used to extract air and water together and will be discussed under "air pumps."

Rotary pumps, consisting of two revolving discs gearing with each other in a similar manner to a Roots' blower, have been largely used on the continent for central condensing plant, but have not been adopted to any extent in this country.

In all types of surface condenser, either centrifugal or reciprocating pumps may be employed. The centrifugal pump has a relatively low efficiency say about 50% on an average, although some makers claim to obtain 60% to 70%. On the other hand it is relatively cheap, an important point when large quantities of water have to be circulated as in surface condensers.

Reciprocating pumps for water circulation are of two main types (*a*) the double-acting pump with positive stroke controlled by crank shaft and flywheel, (*b*) the double-acting pump of the duplex type, designed so that piston makes a short pause at end of each stroke, and as the stroke is not positively controlled the piston may, and often does, fail to make a full stroke. This type of pump is designed to run at a low piston speed say 80 to 100 feet per minute, and is, as a rule, smooth and noiseless in action, but is notoriously wasteful in steam consumption. Attempts have been made to improve the efficiency of the "steam end" by compounding the steam cylinders, but even then the steam consumption is 40 to 50 lbs. per IHP hour, or at least double the consumption of a good positive stroke reciprocating pump.

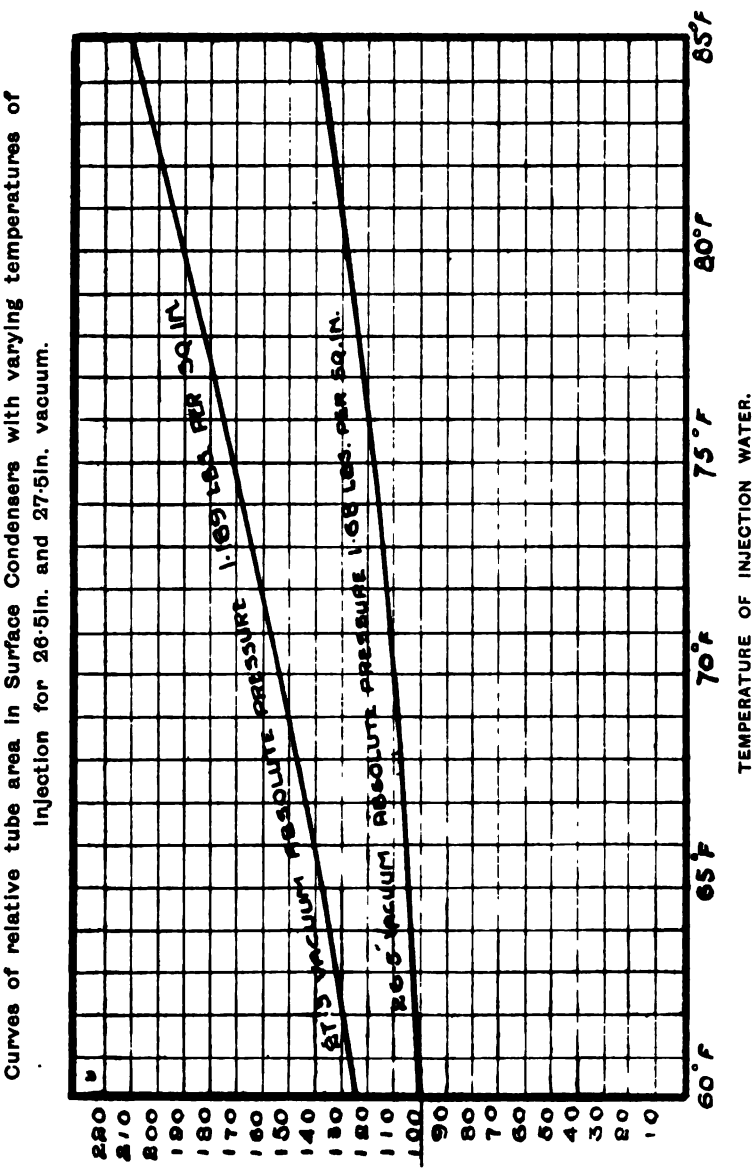

Curves of relative tube area in Surface Condensers with varying temperatures of Injection for 26·5in. and 27·5in. vacuum.
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
60°F
65°F
70°F
75°F
80°F
85°F
TEMPERATURE OF INJECTION WATER.
27·5 VACUUM ABSOLUTE PRESSURE 1·169 LBS. PER SQ. IN.
26·5 VACUUM ABSOLUTE PRESSURE 1·68 LBS. PER SQ. IN.

Fig. 6.

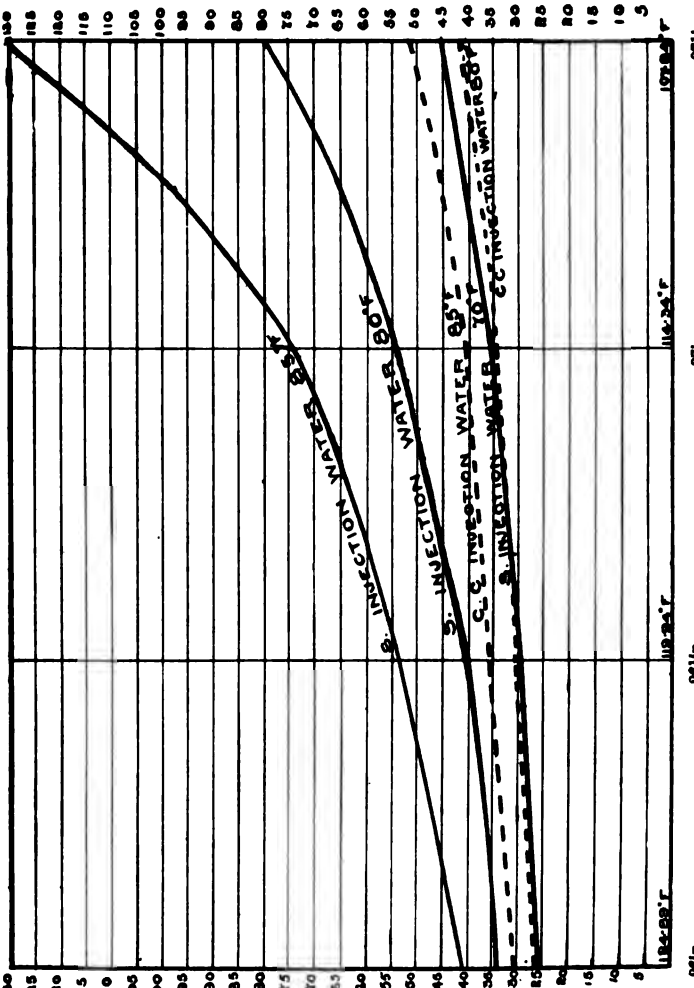

Curves showing relative quantities of Injection Water for Vacuum from 26in. to 27½in.
TEMP.
8. INJECTION WATER 80°F
S. INJECTION WATER 85°F
C. C. INJECTION WATER 85°F
S. INJECTION WATER 80°F
C. C. INJECTION WATER 85°F
Vacuum—26in.
Abs. Press. 1·926lbs.
26½in.
Abs. Press. 1·68lbs.
27in.
Abs. Press. 1·426lbs.
27½in.
Abs. Press. 1·180lbs.
S = Surface Condensing.
C. C. = Counter Current Jet Condensing.

Fig. 7.

For small installations and low vacuums, the duplex or simplex type direct-acting pumps may be used in cases where cheapness in first cost is the main consideration, but for high vacuums where economy of operation is of first importance, this type should never be used.

The double-acting reciprocating pump as supplied by various British makers for independent condensing plants is of the vertical type in most standard designs. Generally two pumps are placed side by side and driven by vertical inverted compound steam engine, the stroke being positive and controlled by crank shaft fitted with flywheel. When supplied with steam at 120lbs. to 150lbs. steam pressure and exhausting to condenser, the steam consumption will not exceed 25lbs. per IHP hour. This type of pump is largely used in electric power stations, where space for condensing is nearly always limited, and is suitable for plants up to 1,500 or 2,000 HP. The worst defect of this class of pump is that in the larger sizes if the floor line is fixed at a level convenient for working engine, the pump casings and valve boxes are below floor level, and generally awkward to get at for overhaul or adjustment.

When comparatively large quantities of water have to be circulated, say 150,000 gallons per hour and upwards, the horizontal double-acting pump, as illustrated in Plates II. and III., has many advantages. In this design there are four horizontal pump cylinders arranged tandem behind a horizontal cross compound engine and driven from piston tail rods. The pumps are worked in pairs, one cylinder from each side delivers to cooling tower, the other two cylinders to counter current jet condenser. In the Klein design of pump, shown in Plates II. and III., the valve chambers are cylindrical casings at each end of pump barrel, with multiple valves set on circular valve plates in casings. The water has a straight unobstructed flow

through from suction to delivery, and the top part of casing is arranged to form delivery air vessel.

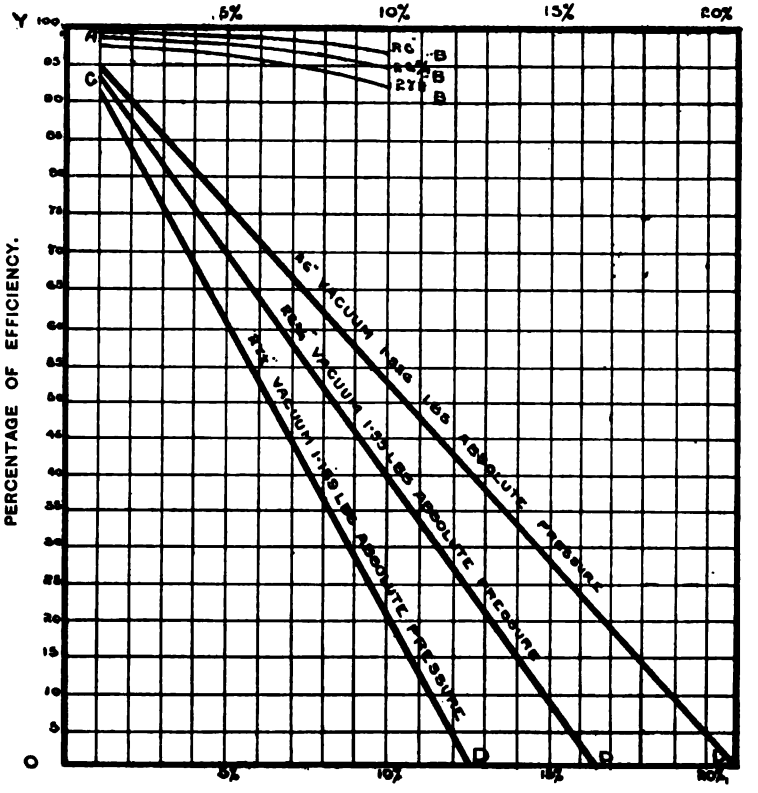
The horizontal design of pump as shown has the obvious advantages that all the valve chambers are above floor level and easily accessible, and that the power for driving pump is transmitted in a direct straight line from steam piston to pump plunger, instead of indirectly through side rods coupling cylinder crosshead to pump crosshead. The compound steam engine driving pumps is generally arranged with slide valve expansion gear, automatically controlled by high speed governor, and when exhausting to the condenser need not use more than 15/16 lbs. steam per IHP hour. The horizontal design is the most efficient type of reciprocating pump, the most reliable in working, and economical in steam consumption. Wherever large quantities of water have to be circulated, and space occupied and first cost are not matters of prime importance, this type of pump is worthy of careful consideration.

The counter current jet condenser may be either of the atmospheric injection, low level type as shown in Fig. 3, or the positive injection, barometric type, as shown in Fig. 2 and Plates II. and III. The former type requires less piping and simpler supports for condenser and is generally used for small and moderate sized installations. When used in conjunction with cooling towers, for which service it is specially suitable, the same pump which withdraws the water from condenser delivers to cooling tower, and must be of the reciprocating type with positive stroke.

For the Barometric type of counter current condenser, see Fig. 2 and Plate II., the water pump may be either reciprocating or centrifugal type, and when used in conjunction with cooling towers one pump or pump set must deliver to cooler and one to condenser. In some cases the condenser is placed at sufficiently high level to permit water to flow by gravity to

troughs on cooling tower, and one pump only is then required, preferably reciprocating type.

The power required to operate water pumps expressed in water HP or pounds circulated and feet head, is least with barometric counter current jet condenser. The total height of lift H in Fig. 2 is say 40ft. in small plants to 44ft. in



Efficiency of Air Pumps with and without equalization of pressure.

Fig. 8.

large plants, but when there is a vacuum in the condenser the atmospheric pressure alone will lift the water through a distance

h corresponding to vacuum, leaving only $H - h$ head on pump, or say about 10ft. for 26·5in. vacuum and 8ft. for 27·5 vacuum.

In a surface condenser for high vacuum about twice as much water will require to be circulated as in a counter current jet, and the friction through condenser water heads, tubes and pipe connections, will be at least 4 to 6ft., and consequently the total power will generally be somewhat greater than for a counter current jet condenser.

Air Pumps.—The principal types of air pump used in modern condensing practice are:—

A. The vertical single-acting bucket pump, with foot, bucket and discharge valves.

B. The vertical or horizontal single-acting pump, with discharge valves only.

C. The horizontal double-acting pump, with suction and discharge valves only.

D. The horizontal or vertical double-acting dry air pump—suction and discharge controlled by single slide valve.

Type A is almost universally used on textile mill engines in conjunction with parallel current jet condenser, and withdraws air, condensing water and condensed steam. It is the least efficient type of air pump in general use, the most difficult to overhaul, and the most liable to breakdown owing to the multiplicity of valves, and the shocks to which it is subjected by dealing with both air and water.

The Edwards' patent air pump is the best known example of type B, and is an excellent pump specially suitable for surface and counter current jet condensers, not so suitable for parallel current jet condensers.

Type C pump is largely used in duplex direct-acting sets for surface and parallel current jet condensers. The valves are fewer in number than type A and more accessible, and when

run at a moderate speed and carefully designed with a positive stroke, it can be used with counter current jet condensers and give good vacuum.

Type D pump is the most suitable design for high vacuums either in surface or jet condensers, and is of the simplest possible construction, there being only a small slide valve for admission and discharge of air, fitted with trick passage which places both ends of pump cylinder in communication at the end of stroke, and thus equalizes the pressure on each side of piston and practically neutralizes the effect of clearance.

For ordinary vacuums a single air cylinder is used, but for high vacuums a two-stage design is now generally adopted consisting of two cylinders of the same stroke but different diameter, the larger cylinder being connected to condenser. In the most recent two-stage design both cylinders are of the same capacity, and it is possible to obtain in the first cylinder with suction flange blanked off, a vacuum equal to ·081 inches of mercury.

When the dry air pump is used in conjunction with a surface condenser it is necessary to provide a separate pump to deal with the condensed steam. This pump is generally single-acting, either horizontal and placed tandem behind air pump, or vertical and worked by coupling rod from engine crank pin.

The total weight of air which has to be extracted from a jet condenser, is derived from three sources, (1) the air present in the water from which the steam was evaporated and brought over by the steam; (2) the air liberated from the cooling water; (3) leakage from pipe joints, relief valves, glands on low pressure piston rod and similar sources.

The highest vacuum possible in any jet condenser in which a given weight of steam is being condensed by a given weight of water, is obtained when the absolute pressure in condenser is practically the pressure equivalent to the temperature. This

result could only be obtained if the air pump maintained a perfect vacuum in the condenser as regards air and that is not practically possible. The absolute pressure in the condenser at any point is therefore the sum of the pressures of vapour and air, and in a counter current condenser the total absolute pressure will be rather greater at the steam inlet end than at the water inlet end of condenser.

The ratio between absolute pressure of air and vapour at any part of the condenser is determined by temperature of condenser, or of water present in condenser, at the given point. At the steam inlet end the temperature is relatively higher, the pressure of vapour greater, the pressure of air less, and therefore its volume greater. At the water inlet end, the temperature is relatively lower, the pressure of vapour less, the pressure of air greater, and therefore its volume less.

From the above reasoning we can understand why the volume of air and capacity of air pumps, is always less for a counter current than a parallel current jet condenser, assuming the same ratio of condensing water to steam condensed, and the same weight of air passing through condenser.

The weight of air to be dealt with in a parallel current condenser is in fact always greater than in a counter current condenser because the ratio of circulating water is greater for the same vacuum.

In a counter current condenser the water and steam flow in opposite directions and if the condenser is properly designed the water will leave at nearly the temperature of the entering steam and thus a minimum quantity will be required. In an ordinary parallel current condenser the water and steam flow parallel to each other, and the final temperature of the condensed steam, the condensing water, and the vapour, mixed with the air which has to be drawn off by the wet air pump, is at a point intermediate between temperature of entering steam

and entering water. The exact temperature at which the discharge water should leave the air pump of a parallel current condenser under given conditions is found quite simply by the engine attendant who moves the handle of the injection tap until he finds the proper quantity of water to give the highest vacuum. This temperature can also be found by calculation. If too much water is injected it brings with it a proportionately greater amount of air which lowers the vacuum, and if too little water is injected the temperature of discharge water and vapour above it is higher, the pressure of vapour therefore greater, the pressure of air less and its volume greater, and consequently the vacuum less. To obtain a vacuum of 26in. in a parallel current condenser, with injection water at 77° Fah. and steam entering condenser at 124° Fah., the discharge water requires to leave at a temperature of 104° Fah. and at this temperature the ratio of air pump displacement to steam condensed will be less than at any other temperature higher or lower.

A simple calculation will show that under these conditions the water circulated through a parallel current jet condenser is 75% more than through a counter current, and the volume of air to be extracted is not only greater by that percentage but also in proportion to its diminished pressure as shown above. An examination of the capacity of vertical single-acting air pumps, designed in accordance with the best practice for large mill engines, will show that the standard pump has a gross displacement about three times as great as the combined displacement of air and water pump in a counter current jet condenser for same vacuum.

Owing to the valves in the bucket, this type of pump has necessarily large clearance spaces and therefore a low volumetric efficiency, probably not more than 50% even in the best designs. In a counter current jet condenser where the air and water are dealt with by separate pumps, these can be designed

exactly to suit the required service and by using the best types an efficiency of 75/80% can be obtained in the water pumps and 90% to 95% in the air pumps.

The vertical single-acting air pump is still largely used in conjunction with parallel current jet condensers for textile mill engines, but for surface condensers, both in marine and land practice, it has been largely supplanted by the Edwards patent air pump. In this design of pump there are no foot or bucket valves. The pump piston is made conical on under side, and at the end of down stroke it uncovers port openings all round barrel, and drives water and air through these openings on to the top of piston to be discharged on up stroke. As there are no valves in bucket the clearance volume at top of stroke is relatively small, a feature which makes for efficiency. On the other hand a certain amount of slip must take place before the ports are closed on the up stroke, and thus diminish the volumetric efficiency. The Edwards pump is undoubtedly a great improvement on the old single-acting pump, although possibly not very suitable as a "wet" air pump for low level parallel current condensers. That drawback is now of little consequence as these condensers are practically obsolete except for very small installations.

For vacuum up to 26in. the Edwards pump is a convenient design for working with a counter current jet condenser, and has been largely used for that service, and has the advantage over the "dry" air pump that it can take a considerable volume of water along with the air without damage. For high vacuum of 27in to 28in., in large condensing plants working on steam turbines, it is necessary to introduce every possible refinement in design in order to keep down first cost and cost of operating plant, and dry air pumps are now coming rapidly to the front both for jet and surface condensing. These pumps being double-acting have only half the cylindrical capacity of a

single-acting pump, and may therefore be cheaper in first cost. They have only one valve for admission and discharge of air, are simple in construction, and easily accessible. The equalization of pressure on both sides of piston, which takes place at end of stroke, greatly enhances the volumetric efficiency as will be seen from an inspection of Fig. 8. In this diagram the divisions on line O X represent percentages of clearance, and on line O Y the volumetric efficiency, or ratio volume of air drawn in to total volume displaced by piston in one stroke. Line A B is curve of volumetric efficiency for single stage dry air pump with equalization of pressure for clearance volumes 1% to 3%. Line C D is curve for air pump without equalization of pressure. The theoretical ratio given in Fig. 8 takes no account of possible slight leakage in piston or slip in valves, and therefore the actual working efficiency is slightly less than shown. The types of single-acting pump with no suction or bucket valves will have clearance volume varying from 2% to 3%, but as they have no equalization of pressure their volumetric efficiency as shown on line C D falls below line A B and may be said to average 75% to 80%. The single-acting vertical air pump with valves in bucket will not have less than 10% clearance and more often 20% or over, and its efficiency is not more than 50% in practice.

In discussing the question of best type of condenser and pumps we have up to this point kept mainly in view the requirements of steam turbine engines as regards high vacuum and limited water supply, but if our argument is sound the deductions therefrom are equally applicable to condensers and pumps for large reciprocating engines as used in textile mills. These engines at present are almost universally fitted with parallel current condensers and vertical single-acting air pumps direct driven from piston crosshead, a combination defective on every point that ought to be aimed at in a first-class condensing

equipment. Calculations made by the writer from a number of typical mill engines show that the gross displacement per hour of the vertical single-acting air pump on these engines is twice or three times as great as the combined displacement of air and water pumps on counter current jet condenser. Not only is the vertical single-acting air pump defective in efficiency, it is also peculiarly liable to breakdown, as the reports of the engine insurance companies plainly show. An alternative design of condensing plant might be suggested, to consist of a counter current jet condenser with separate pumps for air and water, and a water cooler. The condenser to be of the barometric type placed outside engine room, and at such a height that the discharge water would flow directly on to cooler. The pumps to consist of a vertical single-acting Edwards air pump, and vertical double-acting injection pump. The former to deal with air only drawn from the top of condenser, the latter to draw the condensing water from lodge and deliver to condenser. These pumps to be driven from crosshead by levers as at present, or by a small independent engine, or by ropes or belt from a convenient shaft. Alternatively the pumps might consist of horizontal double-acting "dry" air pump, and horizontal double-acting injection pump, driven by coupling rod from crank pin or by rope or belt.

The cooler to be of the open or self-ventilating type occupying about 2 square feet area per IHP, as against 40 square feet area required when cooling is effected by a lodge alone. The lodge could be made larger than nett area required for cooler in the proportion considered necessary to provide adequate storage of water for use in case of fire.

Plates I., II. and III. illustrate two standard types of counter current jet condensing plant. In Plate I. the condenser is of the low level type with independent air and water pumps. The twin air pumps are Edwards vertical single-acting design, the

twin water pumps are vertical and double-acting. The injection water is delivered to the condenser by atmospheric pressure in the usual way, and is drawn from condenser by the water pumps and delivered to natural draught cooling tower. The plant shown in Plate I. was supplied some years ago by the writers firm to condense the steam from engines of 1,500 IHP in an electric power station at a large engineering works, and a duplicate plant has recently been supplied to deal with extensions in generating plant.

In Plates II. and III. the condenser is also counter current but is of the barometric design working in conjunction with cooling towers. The air pumps are of the horizontal double-acting two stage type, each pair being driven by compound engine. The water pumps are horizontal double-acting driven by cross compound steam engine. Two pumps deliver to condenser and two to cooling towers. A similar plant with a different design of water pump is at present on hand for a large electric power station, to deal with the steam from two steam turbo generators, each of 2,000 K.W. capacity.

Thus far our argument has gone to show that where a continuous supply of condensing water has to be obtained by means of cooling towers the counter current jet condenser is the most efficient design which can be adopted for high vacuum. On the other hand there are many cases in which the water supply is limited and is of hard quality, and cooling towers with surface condenser have to be employed. The question then has to be considered for each case, how far will the economy in steam consumption, obtained by the higher vacuum, justify the extra initial cost of condenser and pumps and extra cost of circulating larger quantity of water.

Fig. 6 shows the relative area of surface required in a condenser (Page 437) for 26·5in. vacuum and 27·5in. vacuum with varying temperature of injection water, and it will be seen that with 75°

injection about 50 % more surface is required at the higher vacuum. Fig. 7 shows the relative quantity of water required at the respective vacuum, for varying injection temperatures, and with 75° injection temperature the higher vacuum requires nearly twice as much water as the lower. The capacity of air pump will also require to be increased for the higher vacuum by a considerable percentage. In order to obtain injection water at 75° Fah. from cooling towers under all ordinary atmospheric conditions in this country, it will be necessary to use fan draught, and expend a considerable percentage of the electrical output in driving fans.

Assuming that surface condensing has to be adopted, it is very important that the condenser should be of a design which will permit the water surface of the tubes to be conveniently cleaned at frequent intervals, otherwise the condenser will very seldom work at its maximum efficiency. This object can be obtained either by placing the condenser in an open tank with water circulating round the tubes, or by making the condenser of the ordinary enclosed design with the tubes vertical, and upper water head open on top, so that at any time the water surface of tubes can be cleaned with a hard brush.

The tank or accumulator type of surface condenser has been used in this country for ordinary vacuum on blowing engines working continuously all the year round, a service for which it is specially adapted, but is not so suitable for high vacuum. Plates IV. and V. illustrate a central condensing plant recently put into regular service at a large steel works, to condense the steam from the mill engines and the electric power house engines, the water supply being obtained from a river adjoining the works. The condensers are of vertical design, the circulating pumps centrifugal type driven by compound steam engine, the air pumps horizontal "dry" pumps driven by belt from pulley on centrifugal pump engine. The condensed water

pump and oil separator pump are driven by belt from air pump crank shaft. A similar arrangement, with air pumps independently driven, would be a good design for high vacuum plant working with water coolers.

In view of the great importance of high vacuum for steam turbines, and the difficulty of obtaining sufficient natural supply of water, it is a matter for regret that the theory of condensing has received very little attention in this country, and reliable experimental data are very scanty, even as regards condensers operating under normal conditions, much less as regards condensing plant for high vacuum and limited water supply. In dealing with his subject the writer has therefore had to content himself with attempting to formulate some sound general principles, based partly on theory and partly on his own experience, but as indirectly supporting the line of argument taken in the paper, some data may be given collected from various sources.

The examples given in the accompanying table represent high-class contemporary practice, and are selected to show that when a high vacuum is apparently obtained with standard designs of condenser and pumps, it is got by providing an exceptional amount of tube area in surface condensers, and very large pumps both for jet and surface condensers.

Examples A and B in Table are standard horizontal compound mill engines with parallel current condenser and vertical single-acting air pump of usual design. The actual reading of vacuum gauge gave a higher vacuum in condenser than that corresponding to temperature of ejection, which is manifestly impossible. The readings given are more likely to be correct. The absolute pressure in low pressure cylinder is measured from diagram, and is a much higher pressure, or lower vacuum, than in condenser, indicating too small area in exhaust passages, and possibly even less vacuum in condenser

		A	B	C	D	E
1	Lbs. Steam Condensed per hour..	8,336	18,000	8,616	1,178	1,177
2	Vacuum in Condenser in inches..	27·5in.	26·5in	28·23in.	28·1in.	25·72in.
3	Absolute Pressure in Condenser, lbs. per square inch	·7lb.	1·12lbs.	·82lbs.	·943lbs.	2·03lbs.
4	Vacuum in low pressure Cylinder	25·4in.	25·4in.	25·8in.	24·5in.	24in.
5	Absolute pressure in low pressure Cylinder	2·2lbs.	2·2lbs.	1·96lbs.	2·66lbs.	2·87lbs.
6	Total Tube surface	..	..	1,360	200	200
7	Lbs. of Steam condensed per hour per square foot surface	..	..	6·33	5·88	5·88
8	Temperature of Steam corresponding to Vacuum in Condenser ..	108° F.	120° F.	95·5° F.	100° F.	127° F.
9	Temperature of Hot Well	90° F.	105° F.	90° F.	88·8° F.	117° F.
10	Temperature of Injection Water.	58° F.	75° F.	55·8° F.	40° F.	40° F.
11	Temperature of Ejection Water..	90° F.	105° F.	75·5° F.	64° F.	109° F.
12	Lbs. of Water circulated ÷ Lbs. of Steam condensed..	40·1	39·6	52·5	43·7	15·3
13	Type of Air Pump	S. A.	S. A.	S. A.	S. A.	S. A.
14	Nominal Displacement of Air Pump per hour in cubic feet ÷ cubic ft. of Feed Water per hour	300	228	89	98	98

than given in Table. Both pumps are enormously large in view of the low temperature injection water, and a similar design would be commercially indefensible for high vacuum with injection water at 80° Fah.

Examples C, D and E are surface condensers. C is a marine engine, D and E are different readings from a small land engine. The steam condensed and speed of air pump is the same in D and E example but nearly three times as much water has to be circulated to obtain the 28in. vacuum as compared with the 25·72in. vacuum. The surface in condenser and capacity of air pump in all three cases, C, D and E. are very ample. It will be observed in case C that the temperature of

ejection water is 75·5° Fah. or about the lowest temperature it would be commercially possible to obtain *injection* water in this climate even with a large expenditure of power for fan draught.

In conclusion the writer may be allowed to express the hope that his necessarily limited treatment of this somewhat neglected branch of engineering may serve to direct the attention of engineers and steam users to possible improvements in standard types of condensing equipment, and that his contribution to the Proceedings of the Association may be of some value in indicating the more important factors which ought to control the design of condensing plants for high vacuum and limited water supply.

DISCUSSION.

Mr. R. M. Neilson, said: To his mind, the paper by Mr. Roy was one of the most interesting delivered before the Society for the past few years. He had not studied the paper very fully, but expected it would prove most useful to him for reference.

Mr. Roy had mentioned that there was a want of experimental data as to vacuum, etc. He thought there was a great want of knowledge as to the best vacuum to use in any case. Engineers would greatly benefit, if they knew what was the most economical vacuum to use with any engine and under any circumstances.

For steam turbines it was a comparatively simple matter—they required as good a vacuum as possible—but with reciprocating engines it was different. As the author had stated, it was usually not economical with reciprocating engines to go beyond a certain point. Beyond that point the losses exceeded the gains. Mr. Roy mentioned that it had been found most economical to have a vacuum of about 25in. or 26in. of mercury

for reciprocating engines. One reason why an improvement in the vacuum did not produce the same good effect on a reciprocating engine as on a turbine was that in a reciprocating engine the steam entering the cylinder came in contact with surfaces which an instant before had been in contact with the exhausting steam. The cooling effect of these surfaces on the entering steam would therefore be intensified by improving the vacuum.

Another reason why an improvement in the vacuum did not benefit the reciprocating engine as it did the turbine, was that a reciprocating engine unlike a turbine could not expand the steam efficiently to the condenser pressure. This would require a cylinder of far too great a bulk. If steam was generated at 200lbs. pressure absolute, and expanded adiabatically to 0·6lbs. absolute, 25·5 per cent. of it would be condensed and the volume of 1lb. of the steam and water at the lower pressure would be over 400 cubic feet. It would require a cylinder 6½ft. diameter and 12ft. stroke to contain this single pound.

Mr. Roy also asked, "did it pay to condense?" It did (Mr. Neilson said) in some cases and not in others. There was a very interesting paper read before the Institution of Mining Engineers a short time ago by Prof. Rateau, in which it was mentioned what could be done with engines which could not be worked condensing. Take winding engines in mines. It was not convenient to use these engines condensing. To get the benefit of condensing, Prof. Rateau took the steam exhausting from the engines at about atmospheric pressure to an accumulator, or tower containing trays of water. Steam was conducted from this accumulator to a steam turbine. The turbine ran continuously while each reciprocating engine ran intermittently. If at any instant the supply of steam to the accumulator exceeded the demand of the turbine, the pressure rose slightly in the accumulator, the boiling-point was raised and steam was condensed. If, on the other hand the supply fell short of the

demand, the pressure fell slightly, the boiling-point was consequently lowered and some of the water was evaporated.

With regard to Mr. Roy's diagram (not in the paper) showing the cooling effect of water, would this diagram serve to find out about heating water by means of air, instead of cooling water by means of air?

Mr. Wm. Ingham thought it was more than 30 years ago since Mr. (now Sir) Frederick Bramwell stated that if they had water enough to feed their boilers they had sufficient water to condense with; and they had been a long time coming to their present stage, by which they could now have condensing engines and get a good vacuum, if they had only sufficient water supply to obtain their steam. They had all known for a long time that the air pumps in common use were enormously too large, but it was only of late years that they had been getting data together to show on what lines they ought to go, and they were indebted to Mr. Roy for the very great trouble and pains he had taken to place all this data before them. The advantage of attending a lecture like this was, that they got the pith of a man's extensive reading and experience in a very short time. They would, he thought, all agree that the paper was a very valuable one, and would be one of the most useful amongst their records.

There were, however, many points which were open to criticism. "Vacuum," so-called, was a very interesting thing to talk about. He had once seen it defined in a school-boy's essay as "Nothing, shut up in a box."

Mr. Roy in his remarks about evaporative condensers stated these were going out of use owing to the difficulty of keeping a large number of joints tight, and for "other reasons." He (Mr. Ingham) was rather disposed to think, if such was the case, that it was for "other reasons." He had had some considerable experience a few years ago with evaporative condensers, and

found it was not difficult to keep a large number of joints tight, even at a great distance from the condenser. He had known trouble to be experienced with several, but he remembered particularly one which was mentioned as giving very great satisfaction.

He went to a large colliery in Yorkshire, where this was in use, and saw an evaporative condenser of 1,000 HP., which was said to be doing very well. He saw the mining engineer, who stated it had been invaluable to them. He asked permission to see it, and on going to the vacuum gauge he found the vacuum gauge at 0—there was none. The tubes of the condenser were coated with a layer of salt ¼inch thick, and the incrustation was so great as to prevent any vacuum of any moment being obtained. The advantage was however, in this particular colliery, that they were extremely short of water, and if it had not been for this evaporative condenser, which saved them a large amount of water, the colliery would have had to stop. As it was, they returned the water back to the boiler from the evaporative condenser, and were thus able to keep the colliery running. This saving of water, and being able to work with a very limited water supply, was one of the great advantages of an evaporative condenser.

The data given in reference to the working of non-condensing electricity stations showed that there was nothing so misleading as facts, except figures.

Mr. Roy had referred to four conditions of water supply, and under the first of these, viz., "Ample supply from fresh water river or lake," he suggested a jet condenser as the most suitable type of plant.

He (Mr. Ingham) was rather surprised Mr. Roy had not mentioned ejector condensers in this connection. If they had an abundant supply of good water nothing could beat an ejector condenser, and there were many members present who had had very satisfactory experience with such condensers. The first cost was

small; there was no cost for power as with an air pump, no working parts to get out of repair, and under the conditions referred to he did not know of anything which could beat an ejector condenser such as supplied by Ledward or Korting.

He (Mr. Roy) mentioned that the exact temperature at which the discharge water should leave the air pump of a parallel current condenser could be found quite simply by the engine attendant moving the handle of the injection tap until he found the proper quantity of water which would give the highest vacuum.

It seemed, however, they were now within measurable distance of the time when they would be able to entirely dispense with those large condensing lodges which had hitherto been considered a *sine qua non* for condensing engines, although they still saw large mills and works being erected with enormous reservoirs and dams for cooling the condensing water.

There was one great objection to the evaporative condensers and water coolers in the centre of large towns and cities, and that was the great volume of steam or vapour arising from them. This must be a very great nuisance in some places, such, for instance, as in thickly populated districts. It was rather astonishing to see the cost of 16s. per HP. put down for cooling towers, including foundations and concrete tanks, as compared with £2 10s. to £4 per HP. which had hitherto had to be allowed for the cost of large reservoirs, land, &c.; if this was a reliable estimate it seemed to him there was a great field for these coolers.

That, however, led them to a contemplation of further possibilities in the way of conserving the heat which was at present lost in the steam engine.

They all knew what a comparatively small proportion of the heat generated from a pound of coal was utilised in doing useful work in the steam engine, and many members present would

doubtless remember the attempt made some 20 or more years ago by the introduction of "Marchant's Pump" to return the exhaust steam from the engine direct to the boiler without condensation, the idea being thus to save the whole of the latent heat. This seemed at the first blush very plausible, until it was realised that more work would have to be expended in forcing the steam back to the boiler than could be obtained from it in expanding in the steam engine.

Yet our practice was, up to a certain point, to prevent the escape of all the heat we could by clothing the boilers, steam pipes, and cylinders, &c., and then when they had got the external work only out of the steam in passing through the engine, they dissipated as much of the remainder as they possibly could by running through cooling troughs, reservoirs, and cooling towers in order to get the range between the initial temperature in the cylinder and the final temperature as great as possible.

Mr. Alfred Saxon referring to breakdowns, said: if engineers were asked at the present time, they would say there were not breakdowns enough, either from air pumps, or any other cause. He thought Mr. Roy had made out a good case for the counter current jet condenser, but like all other people who are advocating a particular article, they were sometimes unconsciously apt to exaggerate the merits of the one thing, and exaggerate the evils of the other.

One matter he wished particularly to speak about was the question which had been dealt with in the paper about high vacuum in connection with ordinary reciprocating steam engines.

They were all satisfied, and Mr. Neilson, who was an authority on the subject had told them, that high vacuum was the proper thing to attain to in steam turbines, but they could get too good a vacuum under certain conditions in steam engines. He (Mr.

Saxon) would like to briefly explain that it was a question of the load the engine was driving, that should determine the amount of vacuum that would be most economical. If they had an engine slightly over-loaded, and a great amount of steam passing through, he did not care what the type of the engine was, then they could not get too good a vacuum. High vacuum was a distinct advantage to the engine that was over-loaded, but if the engine was working under load, say at half-load, or three-quarter-load, then it was necessary that there should be a regulating point. An injection valve was applied for the engineer to regulate the vacuum, and to always keep it at the point which was most economical.

The experiments which were carried out by Prof. Weighton, of the Durham University, pointed to the conclusion that a moderate vacuum was the best for reciprocating engines. These experiments were not carried out on proper lines in his opinion, and he took objection to them. The engines were neither regulated for an exact load, nor were they regulated for an exact speed.

The engine which was designed with the most efficent condensing apparatus, was the most valuable engine and the most powerful, but, the vacuum should be regulated to suit the load. That was the point. They should not design an engine for one set of conditions, and have that engine arranged say, with a small air pump and condenser, but they should design an engine on the best and most efficient lines so that it could be removed and placed elsewhere if required to work under entirely different conditions. He thought, as Mr. Roy had pointed out, that there was considerable room for improvement by steam engine makers in this respect, and he would like to say, that the paper read by Mr. Roy showed them what a good thing it was to specialise. The ordinary engineer, in business, tried to cover everything, but the fact was, he could not do that quite satis-

factorily, he had such a wide ground. Even the condensing part of an engine covered a paper lasting about 1½ hours to read, of very valuable and closely written matter. That was only one part of the steam engine, and when an engineer was trying to cover the whole ground, it was impossible for him to make himself into a specialist on all the important items.

He welcomed the paper given by Mr. Roy, as being very valuable for reference. He thought the chief point to emphasise was this,—in the steam engine at any rate, the vacuum ought to be regulated to suit the load passing through the engine.

Mr. James Vose did not profess to have any particular knowledge of this subject. One question, however, occurred to him, viz., why have all textile mills got this type of bucket pump, and so on. There were no keener men, from a financial point of view, than the Oldham millowners, and it seemed to him that there must be some distinct advantage to account for such extensive adoption. The cost of land for condensing ponds in the outlying cotton spinning districts was less than in the large towns, and that might have something to do with it.

There was room for differences of opinion as to the number of "breakdowns." Perhaps there might be something in the simplicity of the common bucket type which commended it to the ordinary millowners, as their own mechanics might see to them from time to time with the aid only of the facilities usually at hand in a mill mechanics' shop.

Mr. J. Ritchie (visitor) on the whole agreed with what Mr. Roy had told them about condensers, but, taking it all round, he believed the jet condenser was the most economical, and quite efficient enough for all practical purposes; still there were occasions, such as in marine practice, where the surface condenser was the only one possible. He agreed with Mr. Saxon's statement, that

perhaps in taking up some particular line one might be rather inclined to say too much of their own article at the expense of something else.

He wished to differ with Mr. Roy regarding the statement on Page 6 of the paper, with regard to surface condensers. His experience has been mostly with surface condensers, and chiefly in marine practice. Mr. Roy states "the condenser water leaves at the hottest part of the condenser where the steam enters." That might be the practice with some builders, but at the same time it was not universal, as he could say from his own personal experience in the firms he had been with and several of the best known firms of the day, among which he might mention chiefly Harland and Wolff, of Belfast, who had for a good many years introduced the opposite from this. Instead of having the condensing water leaving where the steam entered, they had the condensing water entering where the steam enters.

Anywhere on the top of the condenser the steam would enter, and the water would enter at or near the same place, The result was surprising. The difference this alteration made, was such, that in two vessels he remembered, exactly similar ships, working in all conditions the same, and on the same principle, the same engines, and the same condensing plant, but one of them with the injection water entering at the top of the condenser, and the other at the bottom, the temperature in the hot well of the engine where the water entered at the bottom of the condenser, was,—he was speaking from memory,—about 120 degrees. The temperature at the hot well in the other case where the condensing water entered at the top was 140 degrees, so that there was the very great improvement of getting hotter feed to the boiler. The vacuum in both cases was hardly different, he thought 26in., so that on the face of it, the experiment showed that there was advantage to be derived by having this fitted, and Harland & Wolff have, since that time, invariably

made this the common practice. In this matter they have also been followed by the other firm in Belfast, Messrs. Workman, Clark & Co. It was surprising that there were so many surface condensers on the market, when jet condensing was so cheap. He did not understand how it was that engineers pressed this matter forward, unless it was that they expected to make more out of it by selling the more expensive plant.

Mr. JOHN WATSON thought it would be well if Mr. Roy would define more accurately what he meant by "high vacuum." On Page 418 he mentioned 27 to 28 inches of mercury, but they all knew that the atmospheric pressure varied from about 28 inches to 31 inches, or even more, and it would be better to indicate the vacuum in the condenser as so many inches above zero. In certain atmospheric conditions a vacuum of 28 inches was impossible. About four inches above zero was a fairly good vacuum in ordinary engines, and the height of the barometer should always be recorded along with the reading of the vacuum gauge on the condenser.

With the Torricellian condenser here described, and largely used in connection with vacuum pans in sugar works, he had some experience, and had seen gauges on these condensers registering a vacuum within an inch and a half of zero, but in out of the way places where these were situated a mercury column was not available, and when an ordinary gauge is found indicating an abnormally high pressure one is apt to be suspicious that it may be at fault.

When Mr. Roy spoke of air pump clearance, presumably he meant clearance between the bucket and the delivery valve; but this space was always full of water, and so far as the efficiency of the pump is concerned there was no clearance whatever.

Referring to the alleged superiority of the Edwards type of air pump, he wished to point out that it was due to a defect in

the design of most air pumps of the ordinary type which could be easily avoided. In the usual arrangement with the condenser on one end of the foot box and the pump on the other a column of water must be sustained in the working barrel of the pump in order that the bucket might reach it, and this was obtained at the expense of the vacuum in the condenser.

Some years ago a case came under his observation in the tropics where at the starting of an engine the best vacuum he could get in the condenser was 21½ inches. In tropical countries where the injection water was frequently 120° or even hotter, one did not expect to obtain a very high vacuum, but he reckoned there ought to have been at least two inches more, and on examining the apparatus he found it had been so designed that a column of water 24 inches in height had to be maintained in the barrel of the pump, and the vacuum under the delivery valve would be two inches higher than indicated by the gauge on the condenser.

An obvious cure for this defect was to make the bucket descend into a well in the foot box to such a depth that the water did not rise in the pump above the level at which it stands in the condenser.

The paper seemed to him to contain a good deal of debatable matter, but they were obliged to the author for bringing the subject before them in the way he had done. One thing, however, struck him. If it be assumed that by installing an elaborate apparatus an extra inch or so of vacuum could be obtained in the condenser, that would only add about 2% to the effective power of the engine, and one was disposed to ask whether the game was really worth the candle, for in order to get this additional inch the temperature of the condenser must be lowered, and the frigorific effect of this would react upon the cylinder, tending to reduce its temperature and augment cylinder condensation. On this account it was a question how far it was

desirable, from an economical point of view, to increase the vacuum in the condenser of a steam engine beyond a certain point.

The PRESIDENT (Mr. E. G. Constantine) said, among the many other pertinent points drawn attention to by Mr. Roy, there was that where he very strongly hinted that the conditions were not always satisfactory in electric generation stations for condensing, and that this was due to inefficient types of condensers, and pumps, very wasteful in steam consumption. There was no doubt about it, in a separate condensing plant, the steam pumps were very often responsible for an enormous consumption of steam, more than was necessary for the work they do. It appeared also, very plainly, that in a well-designed condensing plant such as Mr. Roy had introduced to their notice, that, combined with exceptional care in the type of pump, a very efficient result could be obtained. He (the President) was strongly of opinion, that with regard to reciprocating engines, high vacuum could be purchased at too high a price.

He remembered in his old sea-going days, he took particular notice of that point, and he found the most economical point at which to work the vacuum was not exceeding 25in. They had to depend on the condensed steam from surface condensers for their feed water, but it was obvious that if the feed water was cooled down to a low point by carrying too high a vacuum, they sacrificed fuel in the boilers; taking it all round, day by day, with different points of vacuum, between 25in. and 27in., he found that the greatest coal economy was secured when the vacuum was not above 25in. That would of course, not apply to the same extent where the feed water was heated between the hot well and the boiler; but where they had to feed the boilers with the condensed steam from surface condensers, and it was not heated by jacket drains or otherwise between the air pump

and the boilers, they could pay too heavy a price for high vacuum.

Like all other apparatus used in connection with steam plants, there was no doubt that the type of condenser which Mr. Roy advocated, had its own particular place, and a very important one, but he did not think it was universally applicable. Taking for instance, marine practice, referred to by Mr. Ritchie, and other speakers, they would not find anywhere, more economical results than in the best types of marine engines working with surface condensers, and a vacuum considerably below some of the points which the author considered it desirable to aim at. The proposition was, however, entirely a different one where the exhaust steam mingled with the condensing water, and suitable means were adopted for heating the feed water. In such instances the higher the vacuum obtained the greater would be the economy.

There were other matters which he would have liked to refer to, but time did not permit, and he would therefore conclude his remarks by asking the members to accord a very hearty vote of thanks to Mr. Roy for the paper which he had given them, and which contained an amount of very valuable information, which would well repay them to refer to it at a later period, when they were in difficulties on this subject.

He therefore moved that the best thanks of this meeting be given to Mr. Roy.

Mr. W. H. Roy in reply said he was obliged to the chairman and the members of the Association for their vote of thanks and their interesting criticism. When he received the usual circular at the beginning of the session inviting a contribution, he had a certain amount of diffidence in offering this paper, because when one read a paper on a specialised subject there was some dubiety as to what extent the matter might be interesting to the bulk of

the members. Although the paper in its title was directly confined to condensing plant for high vacuum with limited water suppy, yet he ventured to think that it might be of considerable interest to those members who were responsible for the design of mill engines, because if the type of condensing plant advocated was a good one it would give the most economical vacuum under all circumstances and with least risk of breakdown. In writing the paper he had had in view mainly the application of condensing plant to steam turbines. Although few of the members might at present be directly interested in the manufacture of steam turbines, they did not know how soon the time might arrive when the turbine would replace the reciprocating engine for nearly all services. He had noticed recently in one of the engineering papers that a large jute mill in Calcutta had placed an order with an English electrical manufacturing firm to take out their old mill engines and put in turbo-electric generators and electrical equipment for driving the mill, and it might not be many years before there was a general movement in that direction both at home and abroad.

Mr. Watson referred to the fact that the barometric or Torricellian condenser had been used in connection with vacuum pans for many years, and he (Mr. Roy) was aware that that was so, and it was surprising that this type of condenser had not been more extensively adopted in other directions. High vacuum might more correctly be described as low absolute pressure, *i.e.*, 27in. vacuum would be practically 3in. of mercury absolute pressure, and this absolute pressure would be the same at all elevations, although the height of the mercury column would vary.

With regard to Mr. Watson's remark that in the ordinary wet air pump the clearance spaces were filled with water, and that therefore they had not a detrimental effect on the efficiency, he might point out that the water in the clearance spaces in a pump

dealing with both air and water was highly ærated, and also was constantly vaporising, and therefore in actual practice the effect was nearly the same as if the clearance space was filled with air only.

Mr. Ritchie made an interesting remark to the effect that in modern practice some of the best marine engine builders were now using parallel current surface condensers. Although that arrangement of condenser was not theoretically so efficient as the counter current, yet under marine conditions where they had an unlimited supply of cold water, and were not particular as to the amount of power expended in operating air pumps, it was possible that they might get better all round results with the parallel current than with the counter current surface condenser.

Mr. Vose said it was rather curious if the old-fashioned bucket pump was so defective that it should still be so universally used, and asked if the writer of the paper could give any reason. Mr. Roy said he could not, beyond the general tendency to adhere to a standard article; but he had hoped in writing this paper that he might elicit a defence of that type of pump from some engineers who still used it in regular practice.

Mr. Saxon said that there was a certain element of exaggeration or at least one-sidedness in the paper. That statement was perhaps justified if the paper was regarded merely as a discussion on the general question of condensing, but taken under the strict limitations of the title, he thought his statements were not too one-sided, and certainly he had tried to be as moderate as possible.

Mr. Ingham had spoken of the evaporative condenser. This type of plant was still being made to some some extent, but was not making rapid progress and did not come within the scope of the paper. He had asked if it was easier to get a good vacuum in hot weather or in cold. So far as the vacuum depended on the temperature of injection water there was not so much

difference as might be imagined in the efficiency of cooling tower under varying atmospheric conditions.

Mr. Neilson had stated that winding engines and other intermittent running engines were not suitable for working condensing. That was not quite correct because in a great many collieries, probably the majority on the continent, central condensing plant was installed to deal with the steam from winding and other engines, but the system was not in general use for collieries in this country.

With regard to the question of the best vacuum, he agreed with the general tenor of the discussion, that so far as reciprocating engines were concerned, the highest vacuum was not necessarily the most economical, especially with limited water supply. He had referred to figures in a previous paper contributed to a kindred society, and might say the conclusions he arrived at then had been obtained by calculating the considerable increase in power required to obtain higher vacuums, which at a certain point outweighed the increased economy. On the other hand there seemed to be no doubt whatever that for steam turbines too high a vacuum could not be obtained. The percentage of saving due to each inch of mercury in vacuum had not as yet been very accurately determined, but appeared to be about 4% of steam consumption.

Independent condensing plant could be supplied to give 27·5in. of vacuum when working with cooling towers, and if the most economical type of pumps were adopted, the steam consumption in pumps need not be more than 8 to 4% of the steam used in the main turbine engines.

In conclusion, he hoped that the paper might be found useful by those members who might at any time have to consider the installation of steam turbine or other engines where a high vacuum was required, and only a limited supply of water available.

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5 Plates follow illustrating this Paper.

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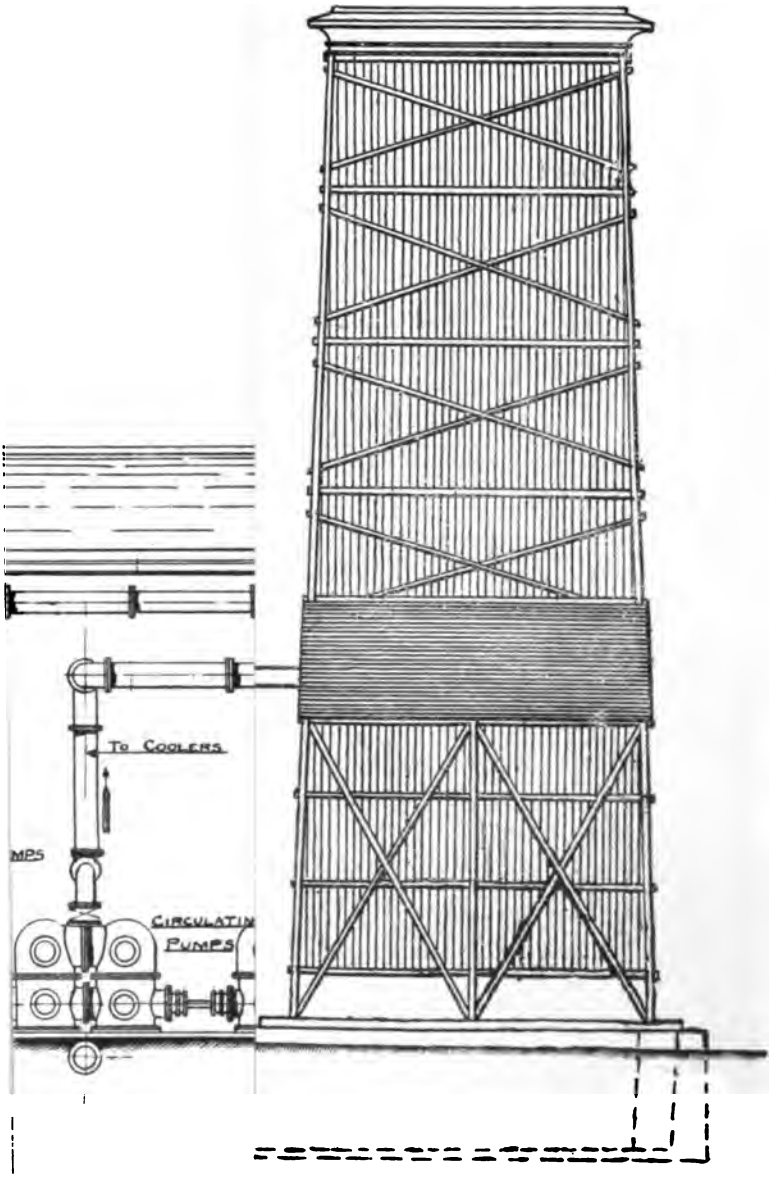
Plate II.

SING PLANT



Counter Current J

UNIV
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Plate II.

SING PLANT

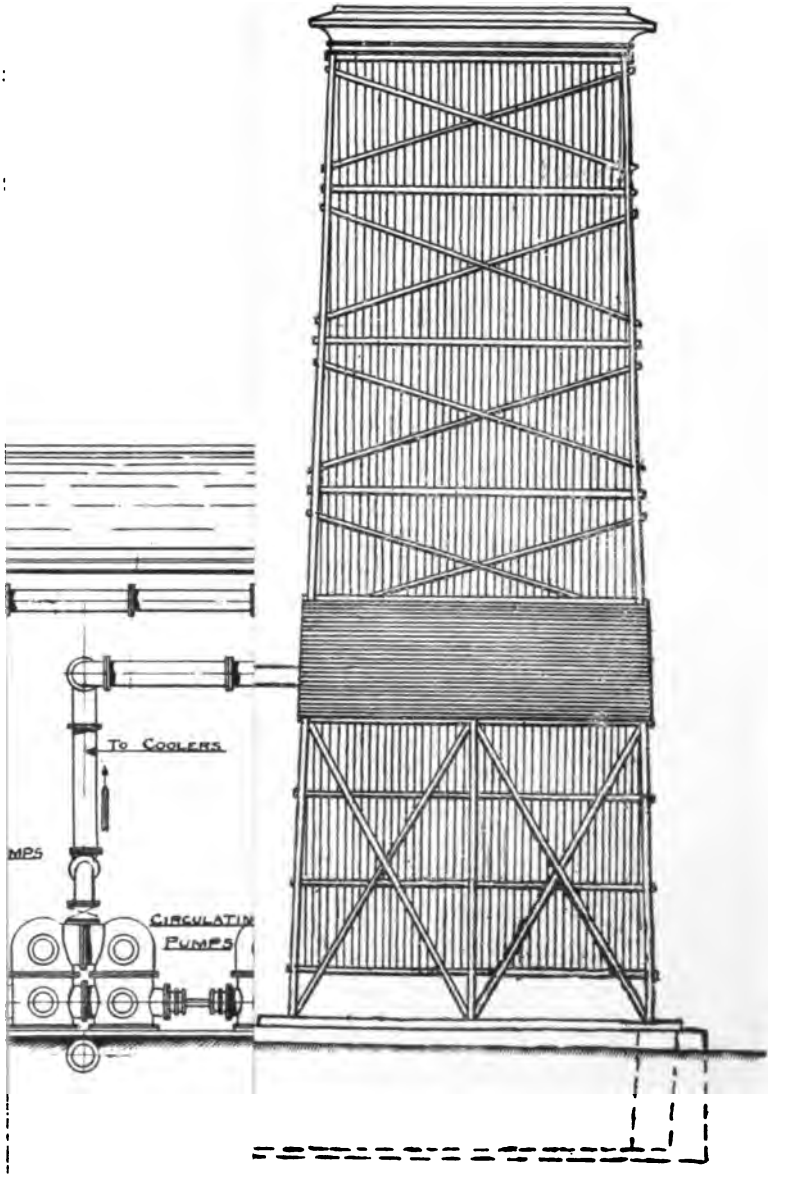

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Plate IV.

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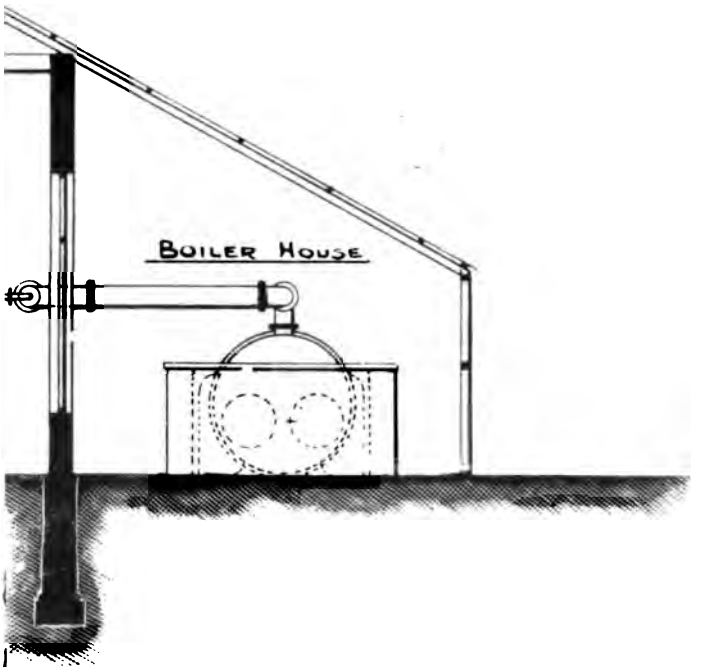

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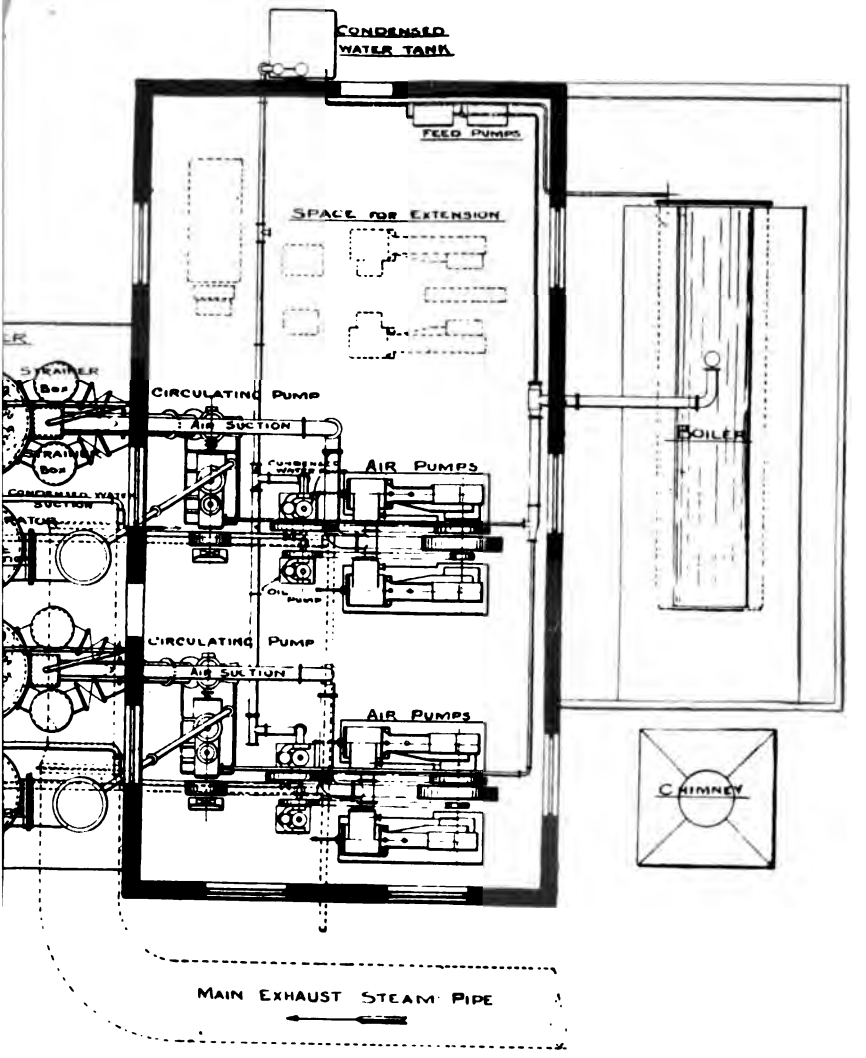


...nsing Plant. PLAN.

UNIV OF WASH.

SOME APPLICATIONS OF COPPER IN ENGINEERING PRACTICE.

READ SATURDAY, 5TH DECEMBER, 1903,

BY

Mr. W. Ed. Storey,

MANCHESTER.

It is a matter for gratification that recognition has been given to the most ancient of the metal trades in the invitation extended to the writer to lay before this Society some particulars of the application of Copper in engineering. The claim for priority of position in point of time is well founded, for even if we waive any direct descent from Tubal Cain as one of the founders of the industry, and some may urge that satisfactory documentary evidence establishing such an origin would be hard to produce, yet in the relics of the Bronze Age, which careful research has brought to light, we have an application of copper long antecedent to that of any of the metals of commerce which in this epoch bulk much more largely in the service of the engineer, but which, as in the case of steel and iron, may by comparison be called the discoveries of yesterday and the day before.

So without apology I venture to bring to your notice a few points in connection with this metal, which the march of industrial development and invention has relegated to a comparatively secondary place, when compared with the enormous application in engineering practice of its baser and more modern rivals.

Further by way of preface let me say that in what follows I confine myself entirely to the uses of copper in mechanical engineering. In the sister branch dealing with electricity copper occupies a more important position, and in the aggregate

is probably used to a far greater extent owing to the enormous developments of the last decade, but this side of the profession is one with which I do not claim to have more than a superficial acquaintance. Moreover, although to the electrical engineer copper is of vital necessity, as may be gauged by the fact that without it the dynamo would be commercially impossible, since he employs it almost exclusively as a conductor of electrical current, the interest in this narrow use of the metal is, in my opinion, but small. So this side of the subject will not be further touched.

A general impression seems to be abroad that, as a material to be employed in the construction of pipes and vessels in connection with steam service, copper at the present time is under a cloud. The conditions under which it is now frequently applied have increased in stringency, particularly along the lines of higher pressures and temperatures; and largely because of a lack of progress in design to meet these conditions, due to a want of definite knowledge of the possibilities and limitations of the metal, as well as on account of the want of an elementary scientific knowledge of the action of various kinds of treatment upon the tenacity and ductility of the metal on the part of the operative coppersmith of the ordinary type, trouble has undoubtedly occured which has shaken the confidence of some of those engineers who are responsible for high pressure steam installations.

I hope to be able to dispel the doubts of any such as may be present by showing how by careful attention to design on the part of the engineer, and to production and treatment on the part of those who combine to supply him with either the materials for his own manipulation or the finished copper products, the advantages which undoubtedly exist in the use of copper and its alloys may be safely utilized by all whom they may concern.

The main claims that copper has to consideration, and in fact to pre-eminence amongst the metals of commerce so far as its special qualities are concerned, are

(*a*) Its high electrical conductivity.
(*b*) Its capacity of conducting heat.
(*c*) Its extreme ductility.
(*d*) Its resistance to corrosion.

Of the first of these we have nothing now to say; the second and third taken together may be said to be of extreme importance to us as engineers; the last also has its interest, but will not occupy us largely on this occasion, as the particular uses of copper for the purposes of the manufacturing chemist, the calico printer and bleacher form again a special line of only secondary interest to this Association. Nevertheless the power to resist corrosion is a very valuable quality in copper in many of its uses by the engineer and will be mentioned in its place.

So then it may be taken that copper earns its place in our regard because of its unequalled power of transmitting heat and its great ductility which enables it to be worked up into intricate forms with ease to the operator and without fatigue to the metal.

Copper, however, in its cruder forms and in the earlier stages of manufacture does not possess either homogeneity, strength or ductility to any marked degree. In fact, as most founders know, it is impossible to produce sound castings in sand from pure copper, the best efforts in this direction resulting in castings having very low ductility and tenacity, whilst they are at the same time porous and full of blow holes. When cast in chills or billet moulds there is some improvement, but without mechanical work of one kind or another being applied, unalloyed copper in the cast state is of very little service.

In studying the structure of metals the microscope plays now-a-days as important a part as does chemical analysis, and

the changes in the nature of copper as it undergoes various processes of manufacture can be very clearly observed by this means. A combination of microscope and camera enables one to record these observations in a manner accessible to all and gives the most interesting results. By the kindness of the Broughton Copper Company Limited I am able to show you to-night a series of micro-photographs which have been specially prepared for the purpose, showing most clearly amongst other things, the structural evolution of the solid drawn copper tube. In preparing these micro-photographs small pieces of copper are cut out of the sample to be examined and are then carefully ground and finely polished; they are then etched with dilute acid under the action of which the structure of the metal is displayed. In the examples given to-night the samples are enlarged to about fifty diameters.

The first of these micro-photographs, marked A, Plate I., shows the structure of cast copper. It will be seen to be irregularly and coarsely crystalline, and mechanically tested possesses a tensile strength of only 10·5 tons per square inch, with an elongation in 4in. of 25%. This result is from a piece of copper cast in an iron mould and is much superior to what could be obtained from a sand casting.

The second of the series, B, Plate I., represents the same material which has undergone a certain amount of work by being forged hot, and it will at once be seen that a great change has resulted from this treatment. The crystals are much smaller and better defined and the mass appears to be much more homogeneous. The tensile strength of this sample is 12·5 tons per square inch and the elongation in 4in. 35%.

The next sample, C, Plate I., is similar to the foregoing but has been subjected to still further work by hot forging and rolling; the crystals in this case are seen to be much finer and more regular and the whole mass much more dense. The improvement in

the structure shows the expected result in the tensile test which gives 14·1 tons per square inch with an elongation of 50% on 4in.

The last example of this series, D, Plate I., shews the effect of carrying the degree of work much further by rolling and cold drawing, and is a sample of a very highly wrought cold-drawn copper having a tensile strength of 15·19 tons per square inch, with an elongation of 48% on a 4in. sample.

A close comparison of the first and last photographs of this series shows with far more clearness than any verbal description could possibly convey, the changes which take place in the process of manufacture of a seamless copper tube and demonstrate conclusively the value of the microscope in testing results. All the samples from which the photographs were taken are of ordinary commercial copper and had been annealed, but I am informed that annealing does not have any very marked effect upon the microstructure.

A second series of micro-photographs has also been prepared with a view to showing the effects upon wrought copper of bad treatment, such as is frequently its fate in the hands of the user either through carelessness in working up or by the nature of its subsequent employment.

Photograph E, Plate I., is taken from a portion of a wrought copper singe plate, which during its life has been frequently raised to a temperature closely approaching the melting point. Originally of a structure similar to C of the foregoing series, it will now be seen to have reverted almost to the structure of A, the original casting, with which it has many characteristics in common. The deterioration in quality due to frequent overheating is very apparent, but is even more clearly so in F, Plate I., which whilst even more crystalline, is seen also to be almost on the point of disintegration.

A far more common cause of deterioration in the quality and strength of copper is illustrated by the Photograph G, Plate I., which represents a piece of highly wrought copper which has been in contact whilst hot with a reducing gas (in this case coal gas). These conditions cause a chemical change in the copper, rendering it brittle, and the effect can easily be produced on the brazing hearth by allowing the fire to be sluggish and short of the requisite amount of air blast. Carelessness in this respect on the part of the workman is one of the most serious dangers copper has to meet, and has, in my opinion, been the direct cause of most of the accidents which cannot be definitely ascribed to such causes as bad design, expansion or water-hammer. By an entire misconception of the cause of this trouble to the copper worker, this state of brittleness is usually known in the shops by the term "burnt copper," and, though some enlightenment is becoming apparent, many workmen still believe it to be the result of overheating. For the sake of exactitude, as well as a means of guidance, it would be better always to use the term "gassed" as descriptive of this condition in copper.

It must be obvious that what constitutes a danger in working copper may, if the conditions are analogous, cause deterioration to copper when in use. The next Photograph, H, Plate I., which I have to show, is a section of a piece of copper tube which has had its external surface subject to reducing gases generated from a fire fed by green coal. It will be seen that the outer surface for a considerable depth has been affected by the action of the gases, whilst the interior surface remains in its original condition.

A good example of copper gassed in working is shown in photograph L. This is taken from a portion of a tube supplied to the writer's firm which had to be swelled at one end to a considerable extent, an operation which entailed frequent annealing. When the bulging was practically completed, small cracks began to develop, and the tube was returned to

the makers as being of faulty material. The micro-photograph which the makers prepared showed at once that the copper had been badly gassed in the annealing, and we had to withdraw our complaint with what grace we could. Had the copper been in this condition on delivery to us it is obvious that it would not have stood bulging at all, whereas we had increased its diameter by more than 25% before the cracks began to appear.

I am sure that you will all agree as to the interest and utility of such micro-photographs as these, by means of which the life history of a piece of copper can be accurately traced and recorded. I have more of them still to show you, but as they more properly belong to another part of my subject I will produce them later.

Copper's virtues, as a material for the use of engineers, have been already alluded to in a general manner. It has to be confessed that there are certain faults attaching to it as a complement to its virtues. Amongst these are the following:—For conductivity of either electricity or heat purity is an advantage, but chemically pure copper has very little resistance to wear. Its ductility forms its most important advantage to the coppersmith and to the makers of plates, tubes, rods, and so forth; but this ductility is gained at the cost of a very low elastic limit. The loss of strength resulting from subjection to high temperatures and to the action of certain gases will have been inferred from the second series of photographs already dealt with. Still, these drawbacks notwithstanding, copper remains incomparably the best material for many purposes in the general practice of engineers.

The locomotive engineer is a large user of copper and, recognizes the many points of advantage it offers in the construction of his boilers. Here the conditions to be met with are quite special: a very high degree of evaporation is demanded whilst the space available is strictly limited, and, the coal supply

being carried along, it is necessary to get the best possible results in steam raising with as small fuel consumption as possible. Copper being so excellent a conductor of heat, the temperature on both sides of the firebox plates is approximately the same even when the fires are forced, as is the case when running. This not only ensures great evaporation, but also reduces the racking strain when raising steam, which would be present if steel were used and which would then result in leaky stays, in the development of fractures and in the consequent frequent stoppage of the locomotive for repair. For the tubes of a locomotive boiler copper or copper alloys present the additional advantage of resistance to corrosion in the case of the compulsory use of bad water, though circumstances sometimes arise in which even with the use of copper tubes pitting takes place. In such cases it may be safely surmised that with iron or steel tubes the trouble would be many times increased.

The chemical composition of the copper used for locomotive fireboxes, stays and tubes has received a great deal of attention, both on the part of the consulting engineer and the copper manufacturer. I have already stated that chemically pure copper does not at all well resist wear, and since in the locomotive working with a powerful blast small particles of fuel are set in motion at great velocity causing a scouring or erosive action, pure copper would not be at all suitable. The addition of a small percentage of arsenic is found to effect a wonderful improvement in this respect, and the various specifications, so far as they relate to chemical analysis, chiefly differ as to the proportion of arsenic the plates or tubes must contain. Arsenic is one of the invariable ingredients of the unrefined classes of copper, and under the circumstances this might be considered a fortunate accident. But so exact are the results demanded by the consulting engineer, both as to chemical and physical tests, the latter closely approaching the ultimate possible, that the copper

smelters have to take no chances, and, first eliminating the native arsenic as an impurity, finally add fresh arsenic in the exact proportions required. It will no doubt be of interest to learn what is demanded on this point by consulting engineers in their specifications of copper, so I have extracted and give in the Table below these details from the specification of one of the leading firms.

I have also been able to get a copy of the specification proposed for adoption by the Engineering Standards Committee at present sitting, and for comparison I extract the similar details from these proposals.

It will be a matter of supreme convenience to the copper manufacturer if this standard specification comes to be generally recognised, as there is reason to hope that it will, for the difficulties, delays and annoyances caused by the small differences existing at the present time between the demands of consulting engineers of equal standing give no compensating advantages to to the buyer and are the cause of much irritation to the manufacturer.

Specifications for Copper and Brass.

Material.	Selected Engineer's existing Specification.		Proposed Standard Specification.	
	Copper Minimum.	Arsenic.	Copper Minimum.	Arsenic.
Copper-plates for Fire-boxes	99·5 %	·15 %	99 %	·35 to ·55%
Copper-rods for Stay-bolts and Rivets	99·5 %	·15 %	99·25%	·15 to ·35%
Copper Boiler Tubes	99·5 %	·2 %	99 %	·35 to ·55%

It was my intention to give as an Appendix an extract of some length from the proposals of the Standards Committee, which would have given, in addition to the details now presented, some interesting information as to tests of brass and copper. I learn,

however, that the report is still considered private, so for the present a comparison of other differences in practice must be deferred.

No doubt the thought is entertained by many that the use of copper for fire-box plates and stays is a very costly matter. The first cost is undoubtedly high when comparison is made with steel at Mr. Carnegie's quotation of "three pounds for a penny." But the certainty of result, the ease of manipulation, the economy in steam raising and the high value of the old firebox when it has ended "its strange, eventful history," all tend to make it the most economical, and in fact the only material for use for this purpose.

For loco-boiler tubes, however, there is room for some differences in practice, and the use of various alloys of copper permits of gains in one direction being set off against losses in another. The first advantage in using alloys of copper for this purpose is the possibility of obtaining by this means a metal which being much harder and stronger than copper can the better bear the heavy collapsing strains, even when used in much thinner gauges: at the same time the co-efficient of conductivity remains high, much higher than that of iron or steel, and the harder quality serves a further useful purpose in resisting the erosive effects already alluded to. The standard practice of British Locomotive Engineers, especially those connected with the great trunk lines, is tending more and more in the direction of the exclusive use of copper boiler tubes.

Where alloys are employed for boiler tubes by far the largest use is made of brass tubes for this purpose, and generally in one of two qualities where copper and zinc are alloyed in the respective proportions of 2 : 1 and 70 : 30. Other alloys also come into play and we have copper and tin combined in Everitt's "Koro" or red metal, which has attained a quite considerable application. Similar alloys of copper and tin have been tried

for firebox plates, but without satisfactory results, the plates showing a tendency to surface cracks on the fire side which quickly put them out of service. The British Admiralty has had for some time the laudable ambition of producing high tension steam and hydraulic tubing, and for this purpose has had extensive experiments made with alloys of copper with aluminium and manganese: but although a large quantity of tubes have been made to meet these new requirements of the Authorities, this departure must still be looked upon as more or less experimental, since time enough has not yet elapsed to prove in actual service the complete suitability or otherwise of the alloys in question. As shewing the effects upon the strength and ductility of copper of the various ingredients mentioned, I give a table of comparative tests which I think will be found to be very instructive.

Table of Tests of Copper and Alloys.

MATERIAL.	Tensile Strength, tons per sq. in.	Elongation, % in 8ins.
Copper: hardened a little by rolling	17·8	27
Do. annealed	14·6	49
Brass: 60/40 annealed	22·8	47·5
Do. 70/30 do.	20·7	60
Manganese Bronze: annealed ..	30·0	15
Aluminium Copper: 5% al. annealed	24·0	69
Do. 8½% do.	31·4	57·9
*Koro Metal Tubes: annealed	17·6	44
* Do. hardened	28·2	5·4

*Average results of two tests.

Eliminating from the foregoing results those relating to the two samples of brass tubes, the others will be seen to be alloys in which copper preponderates to a very large extent and they are all notable as showing the effect of trifling additions of other

metals introducing a hardening and strengthening effect upon the copper. As a general rule copper so treated is less ductile than pure copper, but, as a very considerable ductility is retained whilst at the same time the elastic limit and the ultimate tensile strength are both greatly raised, these alloys present points of advantage for many applications which are worth the attention of engineers.

The same quality of high efficiency in conducting heat that forms its attraction to the locomotive engineer commends copper equally to those who have to provide the means of transmitting the heat of steam to various liquids and substances in the processes of manufacturing and, as a consequence, we have a great variety of boiling vessels, coils, heaters and so forth, the construction of which is the special function of the coppersmith. The design of most of these special appliances is of the simplest form of either cavity pans or coils of tubes and offers little of interest for comment on such an occasion as this. I will therefore pass on to the consideration of the use of copper for steam pipes, where such pipes are exclusively used for conveying steam between two points and are not employed to conduct the steam heat to surrounding liquids.

Some four years ago I wrote an article on "Copper Steam Pipes" for one of the engineering magazines and, as I have seen no reason in the interim to change the views I then expressed, even at the risk of some repetition, I propose shortly to consider again the points that make for utility and safety in the use of copper for this purpose. At that time there was an agitation in certain quarters for the substitution of steel for copper for pipes carrying high pressure steam; it originated in the idea that copper was untrustworthy because of a number of accidents which had occurred to copper pipes both on board ship and in land installations of which more or less condensed reports had appeared in the technical press.

An analysis of the Board of Trade reports of the investigations which followed these accidents went to show that the great majority were due to want of proper provision for expansion, contraction, and vibration on the one hand, and to the lack of suitable arrangements for the draining away from the pipe ranges of the water of condensation on the other hand. This, of course, raises the question of design and should therefore be a subject of considerable interest to this Association. That copper possesses an infinite capacity for sustaining bending stresses is part of the creed of most draughtsmen, and in practice this is seen in the stinting of the dimensions of copper bends, the main object in employing which is to provide for expansion and contraction strains. I have frequently seen copper bends designed on the same lines as would be adopted for cast iron, the centre radius probably only one or one and a half times the diameter of the pipe and with the flanges set as close to the bends as it was possible to attach them. This is wrong for two reasons, the first, because such severe bending of the pipe reduces the thickness of the metal at the back of the bend to a dangerous extent; the second, because a pipe of such short dimensions is far too rigid to have a satisfactory effect in taking up the movement due to expansion. One result of such design is the frequent use, where no real necessity exists, of brazed pipes where seamless pipes could with much less risk be employed, the reason for this being that from plates a pipe can be built up which may have a bend radius very much shorter than is practicable when actually bending a seamless pipe from the straight. I do not wish to be understood to absolutely condemn brazed pipes, for with proper skill and care the brazing process is no more harmful than, say, annealing. But it introduces a risk, which had better be eliminated where possible, since from the nature of it the process is not one of absolute exactitude, with regular temperatures under complete control and it also

depends largely for its success on the personality of the operator.

The difficulty of unequal thickness in a bend can be met better, if the radius is very short, in a brazed pipe built up from plates where an extra gauge can be given to the pieces most likely to be reduced in working; but, if the designer will be fairly liberal in his dimensions of such bends, by making a rule of always allowing a centre radius of three times the bore of the pipe as a minimum, this difficulty in the use of solid drawn or seamless pipes disappears, and the risks are greatly reduced by avoiding unnecessary brazing.

I must join issue with the published statement of two eminent engineers in a manual on marine engineering which they have given to the world. They say, "although brazed copper pipes have occasionally given way, owing to the metal in the neighbourhood of the seam having been 'burned' or over-heated during the brazing, they are, on the whole, preferable to solid drawn pipes, since the latter are not only frequently wanting in uniformity of thickness, but sometimes develop serious longitudinal splits without any warning, even after apparently satisfactory water-pressure tests."

Such a statement given on authority is apt to carry considerable weight with those whose experience is more or less limited. I think it ought to be contradicted, because I believe, as the result of a not inconsiderable experience, that it is the reverse of the real fact. There are, of course, many qualities of solid-drawn tubes, qualities which reflect very accurately the perfection or otherwise of the processes by which they are produced; but given a good and carefully produced solid drawn tube, I have no hesitation in saying that it is more reliable, and offers less risks in its employment as a steam pipe than one which has been brazed. In illustration of this point I now produce my two last micro-photographs. If you will carry your

minds back to the Photograph D already exhibited, you will remember that the structure of a highly wrought copper tube should be very finely crystalline, if it has been subjected to proper treatment. This beautiful structure can, however, only be obtained by a sufficiency of mechanical work. There are processes for producing seamless copper tubes which do not exhibit the same qualities in their products as are to be seen in the example already before you. The process of electro-deposition offers on the face of it an extremely convenient method of obtaining the shells from which tubes can be drawn, but the mechanical work upon the copper above alluded to is reduced in this case, and the results as shown in the micro-photographs are greatly inferior as a consequence. Photograph J, Plate I, is taken from a piece of copper tube made by the electric depositing process, in which the deposited shell is drawn down to a tube $\frac{1}{2}$in. outside diameter by $\frac{1}{16}$in. thick. This, one would think, would give the result of a very highly wrought copper, but as a matter of fact the structure is coarsely crystalline, and more or less on a par with the cruder examples already shown. The other Photograph, K, Plate I., is from a similarly produced tube drawn down to $\frac{1}{4}$in. diameter outside, and here again the same characteristics are visible, though not quite to so great a degree.

The practical purity of electro deposited copper is, as has already been shewn, a positive disadvantage for mechanical purposes, and this would appear to be confirmed by the fact that the purer the copper the coarser are the crystals revealed under the microscope.

A further disadvantage in the use of electro-deposited tubes is the fact that they become annealed at the comparatively low temperature of ordinary steam pressure, and that, also, in a very short space of time.

It will, therefore, be apparent that some discretion must be used in the selection of a suitable seamless copper tube made by

an approved process. This precaution observed, risk and danger are minimised.

There are commercial limits to the application of seamless copper pipes at the present time. At the Paris Exhibition there were to be seen examples of single copper pipes weighing upwards of two tons each and of colossal dimensions. But we may take it that at the moment this is beyond the possibilities of ordinary practice, and would represent a cost that would prove to be prohibitive. Quite recently a specification has been submitted, with an application of tenders, which called for pipes of solid drawn copper, 18½in. bore, $\frac{7}{16}$in. thick and 35ft long, and, so far as I have been informed, there was no one in this country who would quote to this specification. As tenders were also invited in Germany and America to the same specification, it will be interesting to learn whether the buyers have been able to obtain their requirements in these other markets.

The largest pipe of seamless copper which I have personally seen used for steam purposes was one of 12in bore, $\frac{5}{16}$in. thick and 21ft. long. This was bent into horseshoe form for an expansion pipe, and was fixed in a steam range working at 150lbs. per square inch at a tramway electric generating station. This was an expensive pipe, but in all human probability it will last as long as any part of the installation, it will require no expensive attention from the station engineer, as would a sleeve expansion joint of the same size, at the most annealing at long intervals as a safeguard against crystallisation being all that is necessary, and at the end of its service it will be worth at least one-third of its original cost as scrap.

These considerations are daily receiving more recognition at the hands of engineers, and the use of long flexible loops of copper pipe to act as expansion joints is becoming more frequent. There is one point however that deserves more attention than it often gets, when long pipe ranges are provided with two or more

expansion pipes: this is the absolute necessity of providing a firm anchorage for each length so that each expansion pipe has only to take up the movement due to the expansion of the length of pipe with which it is concerned. Failure to notice the necessity of this anchoring of the pipes has frequently, in my own experience, resulted in distortion and fracture of the expansion bends or joints, for it is obvious that, where the whole length of the pipe range is, so to speak, floating, the weakest of the expansion joints will take up the whole of the movement due to expansion, and will probably be stressed in consequence far beyond its capacity. For marine practice, when dealing with stuffiing box expansion joints, Seaton gives the following advice:—

"Expansion stuffing boxes should be cast with the necessary flanges or brackets for securing them to the bulkheads or deck beams, and the end of each length of piping furthest away from the stuffing-box should be anchored in a similar way."

What is good advice for the marine engineer is good also for the land engineer.

The brazing of flanges to copper steam and feed pipes is a subject demanding a little special attention. The material of which the ordinary brazing metal flange is made consists chiefly of copper, with the addition of a small quantity of spelter. This alloy stands a high temperature in brazing, but is soft, and some objection is therefore taken to it on account of the ease with which the flanges are distorted in making the joints. Hard gun metal will not withstand the brazing temperature, which may be taken at somewhere about 1,450° to 1,500° Fah. So the demand for steel flanges for copper pipes has of late become constant. It is not always quite easy to get a good braze between these two metals for various reasons, the chief of which, I think, is that, owing to the greater expansion of the copper pipe than of the steel body surrounding it, the former is forced

into such close contact with the latter in the brazing fire as to prevent the liquid solder thoroughly penetrating. I have seen many examples of apparently sound brazing of this kind in which the solder had really only united the outer surfaces, and had not penetrated any appreciable distance into the joint. Such a flange might successfully stand the usual water test, but would be a source of danger when put to work under conditions of vibration and expansion. To overcome this difficulty the writer's firm some years ago designed a form of flange for brazing which has given every satisfaction under a very extended application. In this flange the internal bore has a recess turned in it which extends almost to the inner and outer faces, but leaves a sufficiently broad band for the pipe to be fastened securely, so as to hold the two together for fitting and the brazing process. From the upper face of the flange, on which brazing solder will be melted, several ducts are cut connecting it to the recess and allowing the molten solder to run into and fill up the recess. At the brazing temperature the solder and the surface copper actually amalgamate, so it will be seen that the ring of solder in the recess firmly amalgamated to the copper pipe forms a key which most securely prevents the withdrawal of the flange from the pipe. A large number of tests have been made to prove the reliability of this joint, and in no case has a flange been forced off without bearing with it a portion of the copper pipe.

The high temperature needed for brazing makes it necessary that the operation be conducted with care and skill if damage to the copper is not to result. The melting temperature of copper is about 2,000° Fah., and, as above stated, of brazing solder 1,500° Fah. There is therefore not a great margin when one considers the fierce blast used in the brazing hearth, between what is necessary for a good sound braze and what is harmful to the copper. The fire must be kept brightly blown, and must

not be sluggish, or else the conditions occur in which "gassing" of the copper results. But given reasonable skill and care brazing is an operation which can be safely relied upon to give good results of an extremely valuable kind.

Before leaving the subject of copper steam pipes there are two more points about which I should like to say a word or two. The first of these is as to the suitability of copper for the modern application of superheated steam. There is not much accurate information available as to the loss of strength in copper under the temperature of say 150lbs. steam pressure with 100° of superheat or, say, a total of 450/500° Fah., but one authority gives this loss of strength at about 8 to 10 % for such temperatures. It follows then that this small reduction in strength is no insuperable barrier to the use of copper under these conditions of temperature, if the application is reasonable and intelligent, and the advantages to be derived from its use on the grounds of its ductility and ease of manipulation will continue to accord to it a fair share of the favour of engineers, notwithstanding the prejudice which seems to exist against it in some quarters at the present time. In this respect the engineer is, in my opinion, travelling, like the lost hunter in the trackless forest, in a circle; he imagines he has left copper steam pipes for ever behind him, but the course of time and events will bring him right back to where he started.

The other point I want to refer to is one of the tests of steam pipes. With a metal the structure of which is so regular and which is not liable to unexplained cracks and flaws, such as are often met with in other metals, and which, moreover, when in use runs so small a chance of corrosion, it is unnecessary, in my opinion, to impose tests of such severity that the strength of the pipe has to be unduly increased and the cost unduly inflated solely on that account. It should be borne in mind that the elastic limit of annealed copper is not more than 6,000 lbs. per

square inch, and no test should be imposed which stresses it beyond this point. Lloyd's rule calls for a water test of two to two and a half times the working pressure, but this is often altogether too much to put on to the work. I remember on one occasion seeing a test of four times the working pressure specified, and this if applied would have distorted the articles in question out of all recognition. Too great a stress in testing may quite probably produce results which detract from, rather than add to, the security supposed to be obtained by testing. Probably the safest way with copper is to use a studied moderation in the demands you make for hydraulic tests.

One safeguard of which users of copper pipes, in situations where considerable stress is experienced, where, for instance expansion movements have to be taken up and vibration to be sustained, should more frequently avail themselves is the process of annealing, which restores the ductility of copper after it has become hard and has developed a tendency to fracture because of the repeated strains that have been experienced by it. This "fatigue" of the metal is known to be suffered also by steel and iron and, as with them so with copper, can be corrected by careful annealing. A systematic attention to details of this kind would greatly reduce the number of accidents of various kinds and would soon re-habilitate copper and restore it to its proper share of the confidence of the expert.

The last branch of my subject which I propose to touch upon in this paper, and in itself this is of sufficient extent and importance to occupy our attention at much greater length, is the application of copper in the form of alloys to the service of the engineer. The alloying of copper and tin was a prehistoric industry; which of the two metals was first discovered is unknown, but from the fact that both, taken alone, are comparatively useless, the discovery of the advantage to be gained by combining the two must have been the work of a

genius ranking in his epoch on a level with Bessemer in later times. One can imagine the pressure of work which would follow at the little foundry of this fortunate inventor as the handicraftsmen and fighting men of his time came to recognise the great advantages offered by these hard bronze instruments, as against those of flint then in vogue, and hastened to bring themselves up-to-date. I should not wonder if the same founder was not, under these circumstances, the inventor also of the "night shift."

The objects which are subserved by alloying copper with tin, zinc, and other metals, are briefly:—the increase of strength, the increase of hardness and resistance to wear, improvement in anti-frictional properties, but chiefly the adaptation of copper to foundry purposes.

The fact that copper without alloy will not cast in sand moulds so as to be homogeneous and of any use in the engineering shops has already been stated; but when alloyed with tin or zinc in a vast number of proportions strong and solid metals of varying degrees of hardness, capable of resisting high hydraulic pressure, easily machined and taking a high polish, can be produced without difficulty. These metals under ordinary conditions do not rust, have excellent anti-frictional properties, and as regards some of them, can be forged or rolled into sheets and bars.

Gun metal and brass are the two terms applied respectively to alloys of copper with tin and with zinc; but the former name has no longer any exact significance. Formerly, of course, it was an alloy of copper and tin which was used for the casting of ordnance, and within my own experience several large lots of old guns made of bronze have been offered for sale in this city, which originated from some of the smaller nations of Europe and, in the fact of their supercession, indicated the stir of modern ideas. The comparative dearness of both copper and tin has resulted in the addition of other ingredients to the alloy which

have less value in order to meet competition, or to secure the founder greater profit, and now the term gun metal only conveys the idea of a brown metal having a copper base. The British Admiralty specification for gun metal to be used for steam purposes is probably well known, but I will nevertheless repeat it. It is as follows: - not less than 10 % of tin, not more than 2 % of zinc, and the remainder of copper of approved quality. The tensile strength has to be at least 14 tons per square inch, with an elongation in 2in. of 7 %. This gives a splendidly sound and tough metal which, however, is rather difficult to machine, at all events at such speeds and with such tools as are commonly used for brass finishing. A small addition of zinc has thus high sanction and is, indeed, necessary to some extent in order to secure homogeneity. Very little lead added to the alloy makes a remarkable difference in the case of working at the price of a considerable reduction in strength, and lead should, therefore be used very sparingly if at all for the gun metal of high pressure steam fittings.

Gun metal is of use only as a foundry metal; it will not forge either hot or cold; its usefulness lies in the soundness and ease with which it can be cast, in the adaptability with which it can be varied to suit many requirements, its high elastic limit and its great homogeneity. Carefully prepared alloys cast in sand will give results as high as 16 tons tensile strength per square inch, with an elongation of 10 to 12 %.

Brass has innumerable uses outside the domain of engineering, but even within these narrower limits has a very wide application. It has great ductility, but at the same time great strength and a high elastic limit. According to its content of zinc it can be forged hot or cold. Brannt gives the limit of cold rolling or drawing as lying in a proportion of 37 % of zinc, but I think this is higher than actual practice would allow, and 34 to 35 % of zinc is more nearly the commercial limit for com-

bination with copper for cold rolling. For forging hot, upwards of 40% of zinc may be used in the alloy, though the ductility of the metal is reduced the higher the zinc content. The "high speed turning brass rods," so much used in these days of automatic machines for making screws and small details for machines, contain a small proportion of lead to make the operation of the tools easier, and to reduce the heat which would otherwise be a source of trouble. Speeds as high as 2,000 revolutions per minute are used in turning small articles made from this kind of material, and at this speed the metal works freely and does not need the application of soap and water, or oil to keep down the temperature.

The British Admiralty employs very largely a brass containing one per cent of tin, and called "naval brass," in situations exposed to the action of sea-water. This metal has been introduced, as the result of many trials, to overcome the difficulty of pitting in condenser tubes, a trouble, which, although more or less an every day experience of the marine engineer, is also not altogether unknown in other branches of the profession. Pitting seems to take place chiefly in tubes used in connection with foul or impure circulating water, such as is found in river estuaries near large towns, or in such waterways as the Ship Canal, and the old practice of tinning internally and externally, which was at one time thought to be a complete protection against corrosion, has been found to fail to answer this purpose. Probably the extended use of electricity on shipboard has had bad results in the direction of increasing corrosion by electrolysis, and in any case the conditions necessary to the setting up of galvanic action are often present where impure water is used. I am informed that in vessels almost wholly navigating the deep seas the trouble caused by pitting in the condenser tubes is much less frequently experienced. Corrosion due to electrolysis is not confined to condenser tubes however, and I have seen

examples of valve spindles and pump rods in which the zinc portion of the alloy has been almost entirely eaten out, leaving a spongy mass of almost pure copper on the outer surface, increasing in content of zinc till at the centre the original alloy remains unaltered. The addition of a small percentage of tin seems more or less to correct this tendency, and the Admiralty at all events is satisfied with the efficacy of this addition, since all the material for condensers, bolts, nuts, and so forth for under water fittings, is now specified to contain 1 % of tin.

Condenser casings whether cast or built up from plates are required to contain 62% copper, 37% zinc, 1% tin; condenser tubes 70% copper, 29% zinc, and 1% tin Owing to the exigencies of manufacture, plates and rods have to be hot rolled, whilst tubes have to be cold-drawn; this accounts for the differences seen in the specifications. Were it possible to ignore the necessities of manufacturing it would be preferable to have all the materials for the condenser of the same alloy, so as to keep as far as possible away from the chance of setting up conditions favourable to galvanic action. Naval brass is an extremely strong metal and forges well at a dull red heat. The Admiralty specification for tenacity and ductility in this metal calls for 28 tons tensile strength and 15% elongation.

The last group of copper alloys to which I propose to allude and that only very briefly, is that generally known under the designation of high-tension bronzes. These are almost entirely formed of a base of copper and zinc in much the same proportions as are employed for the production of brass or yellow metal, but in addition they contain a small percentage of either manganese, iron or aluminium, or even of all three together. The effect of this small addition of these particular metals is to produce results of the greatest importance. As compared with selected samples of brass, a rolled manganese bronze rod will give results up to 50% increase in tensile

strength, whilst at the same time exhibiting superior ductility. Both manganese bronze and aluminium bronze can be cast if due precautions are observed, and I was recently informed of a test made of the former, cast in dry sand, which gave a tensile strength of 38 tons per square inch with an elongation of 18% in 2 inches. The metal is not easy, however, to cast successfully and requires special attention and practice, so that the best results are not always obtained until after a number of failures have pointed the way to success. The very general adoption of these alloys for propeller blades and similar large castings demanding great strength for uses in connection with shipbuilding shows that with proper treatment these difficulties can be overcome.

Manganese bronze also presents a most determined resistance to corrosion, far exceeding that shown by most other kinds of brass, either cast or rolled. It is therefore much used for pump rods, for which purpose it is also especially suited because of its great strength and the ease with which it can be forged, for bolts and studs, valve spindles and the like.

Two instances of the application of this bronze to situations of severe difficulty on account of corrosion may be of interest and with these I must close. The hydraulic power main conveying the power to the railway swing bridge at Trafford Wharf on the Ship Canal has to pass across the bed of the canal under water. The main is of copper and the flanges are bolted together with manganese bronze bolts and nuts. The main was laid in 1895, and I am informed that it has never given any trouble since that time though constantly under a pressure of 70 lbs. per square inch. To anyone who is closely acquainted with the corrosive nature of the water in this part of the canal, no further testimonial would be needed.

The other typical case is an application of manganese bronze in the galvanizing department of a wire mill, where a special form of sling to carry the coils of wire for immersion in the

pickling trough was forged out of a bar of bronze. This exceptionally heavy duty was admirably performed and the same resistance to corrosion could be instanced in many cases if time permitted.

In concluding I have to express my regret that my paper has had to be so sketchy, and also, I fear, in some respects, so elementary and so obvious. One reason for this is the extent of the ground sought to be covered, which only permitted of a slight outline of some of the branches of the subject. If, however, what I have written has been of any interest, will provoke a closer attention to the merits of copper as a material for much good service to the engineer, and will help to remove any prejudices which may exist against its employment on an even wider scale, my objects in submitting this paper for your consideration will have been amply fulfilled.

DISCUSSION.

Mr. Wm. Ingham said amongst those interested in the trade there had long been an impression that if there was any firm who knew anything about copper, it was the firm of Isaac Storey and Sons, and the paper they had just listened to from Mr. Storey certainly confirmed that impression. Until the results of very elaborate experiments and tests of copper which were made by the Board of Trade, and published some 15 or 16 years ago, after the disastrous explosion of a copper steam-pipe on the s.s. "Elbe," they had very little reliable data to work upon.

Mr. Storey had referred to "Everitts" metal. He (Mr. Ingham) had a distinct recollection of this being first introduced as "red metal," and of having applied to Messrs. Storey's firm for information about it. The qualities claimed for it at the time appeared very much superior to what was generally thought

possible. He had an impression that subsequent experience with it (especially in locomotive smoke-tubes) had shown it to be not so satisfactory as was at first anticipated, and he would be glad to hear from Mr. Storey whether that was the case.

Mr. Storey had not referred to galvanic action. One objection to the use of copper was that, wherever it came into contact with other metals, such as wrought iron or steel, very serious wasting and deterioration often took place from galvanic action. That was an important question which, he thought, might have been referred to in the paper, and the best means to take for counteracting it. Reference had been made to the chemical changes which took place where highly wrought copper was brought in contact, whilst hot, with a reducing gas, such as coal gas. It would be interesting to hear the results of any investigations that had been made with regard to the analysis of the brittle portions, and whether it was the formation of cuprous salts that rendered the metal so brittle.

With regard to locomotive fire-boxes, it was the practice—more in England, he believed, than anywhere else—to use copper. In America, steel fire-boxes, he thought, were generally used. The wonder over here had been, why they had had such a long run in the States, and why copper had not been more generally used there. With regard to the high value of the old copper fire-box of a locomotive boiler after it had ended its "eventful history," he might mention that many years ago it came within his (Mr. Ingham's) province to settle claims for damages from overheating and explosions of steam boilers, and he had a very vivid recollection of one case of overheating of a locomotive copper fire-box, which they expected would result in a very heavy loss. When they had made a full assessment of the damage sustained, however, he raised the question of the value of the old copper fire-box, and this was found to reduce the claim very considerably, so that he could quite endorse what Mr.

Storey had stated as to the value of the old copper in the fire-box being a good asset.

Mr. Storey referred to the irritating demands of consulting engineers. There were, however, two sides to this question, and if every firm in the trade had been as reliable and straightforward as Messrs. Storey's, there probably would not have been that absolute discretion placed in the hands of consulting engineers that there had been. But with unprincipled contractors, who undertook work at a low price, and who tried to compensate themselves by "scamping," it was necessary to lay down very stringent conditions to guard against that unprincipled evasion of the terms of the contract which is so often attempted.

He was very glad to see the elastic limit mentioned. If they could get the elastic limit of a material, they would never be far wrong by working up to say one-half that limit. They had great difficulty often in finding what was the precise elastic limit of a particular material. He was in entire agreement with Mr. Storey as to the comparatively little value of hydraulic tests, which were often very misleading. The question was put to him in the witness-box by counsel a fortnight ago, as to what the fact of a structure having withstood a water pressure of 20lbs. per square inch would convey to his mind. He replied, it would show that it had withstood 20lbs. hydraulic pressure. Nothing more. The danger of relying too much on hydraulic tests arose from the fact that when the structure came into practical use, it was often subjected to entirely different conditions. Strains from vibration, shocks, expansion and contraction, etc., were introduced, which had the effect of bringing about failure at a much lower pressure very often than that which a vessel had apparently withstood satisfactorily under hydraulic test.

Vessels were sometimes tested to such a degree as to render them quite unsuitable for the work for which they were required,

after they had been severely strained by being subjected to a very high water pressure.

He thanked Mr. Storey for the trouble he had taken in preparing and reading the paper, and hoped he would be able to visit them again at some future time.

Mr. THOMAS ASHBURY congratulated the Society upon having such a paper given to them on a subject of which many of them desired some reliable authority describing to them the effects of the use of copper under certain conditions. He was quite confident they could not have got any expert to have gone more thoroughly into the subject, and to give them the desired information, than the representative of that famous firm they had present with them.

They must agree with Mr. Storey in his conclusions, but he thought there were a few things which came in the use of various metals to which they might give special attention. And one was galvanic action. That had upset many calculations, and introduced trouble in many cases. This was only hinted at in the paper, and he would like to know more on that particular subject. They were beginning, with these illustrations before them, to understand the construction of the metals and their behaviour under certain conditions, and under varying temperatures in daily experience; and, as had been stated, that information would have been invaluable 20 or 30 years ago.

He once heard a very distinguished man – one of the greatest living authorities in the iron and steel industry—say, not very long ago in London, that it seemed to him, after having microphotographic illustrations like the present ones before him, that his experience of 50 years had all gone for nothing. He (Mr. Ashbury) felt they were just beginning to see the inside of the material that they had been working upon for the most of their

lives. Personally, he thanked Mr. Storey for being with them, and for the very valuable information his paper contained.

Mr. SAM BOSWELL said Mr. Storey had very rightly said "copper was under a cloud," and in his (Mr. Boswell's) opinion it would remain so until the users of copper made up their minds to have this class of work done by the proper people; by which he meant such firms as not only fully understood the nature of the material dealt with, but who kept such men as could be relied upon to do a satisfactory job when entrusted with it Specifications were often so framed that loopholes could be found in every page, people who never ought to touch copper work quoted at such ruinous prices that the honest coppersmith had no chance whatever, the consequence being the material was pinched or scanty while the work was rushed by inexperienced men. Since he had been able to form any opinion as to the virtues of metals he had concluded that the great virtue of copper (namely, that it was fairly easily worked) was its greatest downfall. It was, when properly handled, one of the most valuable and accommodating metals, but when pranks had been played with it, it was, perhaps, the most wicked. Any plumber, tinman, mechanic, or even blacksmith, thought he could bend and braze a copper pipe or set a flange. He did, but he did not know the damage until something happened. Even to-day a contract had been let in a Lancashire town in which copper pipes figured largely, and he believed the plumbers were not only claiming this as their work but threatened to strike if this work was not handed over to them. Where did the coppersmith come in, he would ask, if not on such a job, where there were hundreds of pipes and bends to set and adjust? When such matters were clearly defined respectable coppersmiths would have a chance.

Mr. Storey spoke of "fatigue." In his opinion depreciation of a metal during working did not come under the head of

"fatigue" in its generally understood sense. If badly worked, overheated, or its quality otherwise impaired, it was "punishment;" while the way men were instructed to carry out work of this description occasionally laid the responsibility on the shoulders of the supervising engineer.

As regards copper fire-boxes for locomotives there was no doubt that under the present system and conditions of working, copper was the correct thing and worth all the additional cost: its greatest virtue in his opinion being that the copper surface refused to accept too close a relationship with the deposit. As deposit formed, it shelled off, and the narrow spaces were therefore more easily kept clean. Of course there were exceptions in this respect, but they were only few. With copper a better stay-end could be had than with steel, the portion of the tube-plate carrying tubes were increased in thickness to give strength between tubes and at the same time give a better bearing for tube ends, which was of importance, without the whole plate being unnecessarily thick.

Steel fire-boxes were used on the Continent and in America, but it was somewhat doubtful whether they were subjected to the same hard wear and tear with indifferent feed-water experienced in this country. He did not think it would have been possible for the famous L. & N. W. engine "Charles Dickens" to have run 4,000,000 miles without repair, if a steel box had been in use.

Copper in fire-boxes had its disadvantages, owing chiefly to its softness, and the action of sulphur, but these were not great or fatal to its use. When no longer useful as a copper fire-box, it was generally looked upon as good scrap, but it was surprising how little there was of the box left. He had cut copper boxes out and found what had originally been $\frac{1}{2}$in. reduced to less than $\frac{1}{4}$in., especially from the bottom to 3ft. upwards.

If a loco was at work under fair conditions and regularly washed out, he believed a steel box could be made to stand satisfactorily.

As regards brazing, he thought there was a great risk indeed, due to the over-heating of the metal. Men of many trades had occasion to do brazing, and with iron to be joined and good spelter to use, the engineer, or perhaps plumber saw little risk, as even hard spelter would flow long before the iron pieces suffered, but with copper it was much different, and there was many a time when the spelter needed almost the same temperature to melt it, thus giving a narrow margin between melting the spelter and over-heating the copper.

In the solid drawn tubes there seemed to be great tendency to splitting as shown by Board of Trade reports.

He was glad to hear Mr. Storey's remarks anent expansion joints, and the method of anchoring them so that each joint had its own work to do, and that only. He believed the first time this anchoring of steam pipes to the expansion joints was first applied to the main steam range of the Galloway boilers where it gave every satisfaction, and wherever since adopted no trouble had been experienced from expansion and contraction. Without anchoring it is only to be expected that with two or more expansion joints, the whole of the work will come upon the weakest of the series, and trouble soon follows.

Mr. Storey had mentioned fatigue in copper as compared with iron. He (Mr. Boswell) was not so sure about copper, but he had tested iron-plates that had been at work in a boiler in Cornwall over 100 years, and he was surprised to get results equal to "Best Best," or even "Treble Best" iron of to-day; thus showing that the samples had suffered very little indeed from fatigue.

He now came to the parting of the ways, or at all events to that point where he differed from Mr. Storey. He was an

advocate for mild steel steam pipes, but could scarcely expect Mr. Storey to be other than an advocate for copper. Steel, in Mr. Boswell's opinion, would always give better results than copper. As regards the reports of the Board of Trade he had read every Report issued (about 1,459 in all), and he did not think they proved that "bad design" was accountable for all the accidents.

Copper pipes, &c., seemed to show nearly 10% of the total explosions reported on.

Explosion No. 1,419; copper pan 10 years old; cause:—"it had become too weak at the seam." This can only be put down as fatigue.

A brewers copper failed after five years, due to "bad brazing."

No. 1,426 was a pipe 10ft. long by 5½in. dia.; at work seven days; flange tore away. This was a bent pipe of one continuous curve, so that it could not have been rigid.

No. 1,453 was said to have failed "through vibration" after 10 years. It was 7ft. 5in. long and bent nearly to a half circle.

No. 1,454 was said to be "due to wasting." 1,459 was another case of wasting after four years work. These copper pipes crop up under all sorts of conditions—"weakening," "vibration," "bad brazing," "loosening through high temperature," and "overheating when being repaired." None of them seemed to him to come under "bad design." In these investigations the same people were responsible for design that had to do with the investigations, therefore "through insufficient provision for expansion and contraction" was only what might have been expected.

As regards age they ran 1, 2, 8, 4, 10 and 12 years and so on. One was said to be bad brazing though it had lasted 12 years. Nearly all the pipes that had gone wrong were arranged with easy bends 3 or 4 diameters radius. For steam pipes he did not think copper was the best material that could be used, but so

long as copper pipes were so specified that the unscrupulous could get it, it would still remain under a cloud. Mr. Boswell asked if leaving copper pipes naked would not tend to keep down fatigue; it would certainly mean a loss in economy, but the copper being kept at a lower temperature would not suffer so readily.

Mr. GEORGE SAXON said that with regard to copper pipes for high-pressure steam, or super-heated steam, Mr. Storey seemed to have a desire to compete with the steel steam-pipes, now adopted for that purpose to a very large extent. Copper had been a very valuable servant to them in the past, but it had to give way, in many matters connected with engineering, to the later development, and the more efficient manufacture, of steel pipes for carrying steam. Mr. Storey need not be afraid of the copper industry dying away, because he had told them in the paper of the very great utilisation of copper in electrical engineering and electrical connections.

It seemed to him that manufacturers had to consider price as well as the quality of the material, and if they could get as efficient a material for their use, and at a cheaper price, naturally, for mercantile reasons alone, they would adopt the one that was cheaper in the first case. That was the temptation to the buyer. It might be all very well for Mr. Storey to state that when the copper came to the scrap heap that they could get a large element of the cost back, but that did not appeal to the buyer. He looked at the first cost, and if he could get an article that would give him the same advantage, or an equivalent, he was only too willing to adopt it.

It seemed to him, and as stated by Mr. Boswell, that the weakness in copper pipes was very largely due to the brazing, and in many cases, if they could avoid the brazing of the pipes, a weak element would be eliminated. This was more particularly

so in connection with, say, an ice plant, where ammonia was used. The ammonia was so very searching that it affected the brazing the very first thing. Assuming the copper pipe to be properly made, the brazing was the thing that would go first. That indicated that anyone putting copper coils under the influence of ammonia in an ice plant ought to avoid as many brazings as possible.

Mr. FRANK PROUT remarked that some time ago he was connected with a shipbuilding firm doing Admiralty work, in which all copper pipes were wire-bound. He would ask Mr. Storey's opinion on this subject. Did the wire-binding add strength to the pipe, or was it only a safeguard against flying pieces in case of an explosion? His own opinion was that the latter was the only benefit derived from wire-binding.

With regard to expansion loops. A case which came under his supervision was an expansion loop with very short bends. This was tested to 250lbs. water test in the shop; again tested in the ship before steaming. After 24 hours' steaming in a heavy sea, and consequent vibration in the ship, the loop split on the outside of one of the bends at a working pressure of 98lbs. per square inch. On examination the copper, which was $\frac{1}{4}$in. thick where not bent, was only $\frac{1}{16}$in. on the long side of the bend. This confirmed Mr. Storey's remarks.

Another case was a built-up copper bend, the joint being dove-tailed. This failed owing to the dove-tailed joints not being a good fit, and the interstice being filled up with brazing, the result being that under steam-pressure a portion of the latter blew out.

Mr. WALTER HEAP observed that they all spoke of copper from their own point of view. He thought that by putting mechanical work into copper it improved it, both in hot forging and hot rolling.

Mr. Storey said cold rolling also improved it. The cost of copper, compared with other material, was certainly very high, and it was the aim of the engineer to economise in such high-priced materials as much as possible. He had made copper stays from blanks $\frac{1}{16}$in. less in diameter than the finished stay. Say a stay was to be 6½in. long × 1in. diameter, with a neck in the centre 3½in. long; he would take a piece of copper 6in. long × $\frac{1}{16}$in. diameter, and he rolled the neck in, making it ½in. longer, and then rolled the thread on each end, making it $\frac{1}{16}$in. larger in diameter. Mr. Storey would bear him out that the cold-rolling had improved that stay. The cold-rolling increased the elastic limit at least three times. But as this high elastic limit was not required, the blanks were annealed after the neck was rolled in. The idea in rolling fire-box stays was to save the copper, and give them better threads. Instead of cutting the fibres of the copper by screw-cutting, the fibres were simply rolled and bent, and not cut. By the annealing, he got the same ductility as in turned stays. There was also the additional advantage of a great saving in copper, amounting to 10%. He thought the more mechanical work put into the material, the better it was, and for that reason he worked out this idea for copper stays, and put more work into the material. It improved the quality of the metal, and produced a stay for much less money for material, and also much quicker than it could be turned and screwed.

Mr. THOMAS WHITEHEAD remarked that there was no doubt mechanical work was one of the most important factors in the manufacture of copper, and especially so in the first stages after melting. To prevent the formation of the coarse crystalline structure always found when copper was cast in open moulds, the firm with which he was connected had for many years made all their castings under pressure. This, followed by hydraulic

forging, hammering, and cold drawing, gave a fineness of fracture unobtainable by any other method.

He had brought to the meeting some micro-photographs which had been taken by a well-known Sheffield firm from sections of copper rings supplied to them by different manufacturers, and supposed to be of equal quality, but they would see from the photographs how different had been the amount of work put upon the various specimens. No. 1 was extremely coarse and granular; No. 2 decidedly finer, and better worked; but No. 3, made by his firm, was far superior to either of the others. See Plate I.

In the manufacture and working of copper, there was nothing more important than the annealing. More copper goods were spoiled in annealing than most engineers suspected. Copper, when hardened by hammering, rolling, drawing, or other mechanical work, and then annealed, began to soften at a temperature of 550° Fah., and was completely softened or annealed at a "faintly perceptible red" temperature of 800° Fah. A higher temperature than this "faintly perceptible red" was unnecessary, but it might, without mischief, be increased to a "dull cherry red," or 1,650° Fah., as up to this heat no further change took place in the copper. It was made no softer, and had the same tensile strength; gave the same elongation and the same reduction of area when tested. When copper was heated above a "dull cherry red," or more than 1,650° Fah., it became weaker and coarser, and with continued increase of temperature, the coarse structure increased until the metal became quite rotten, and finally melted at about 1,950° Fah.

He did not propose to follow the remarks as to the strength of copper steam-pipes, further than to point out it was evident, from what he had just said, that within the range of temperature known to steam-users, copper was not affected below the strength of annealed copper. There was no further loss of strength.

With regard to sizes of tubes mentioned by the author, these could now be had from local makers, 10in. diameter up to 80ft. long, and smaller diameters in longer lengths, to 1in. diameter × 100ft. long.

There were other uses of copper in engineering of which no particular mention had been made, although of very great importance. Although somewhat costly in the first instance—and those who wanted a good article must face the price—copper pipes were unequalled for hydraulic purposes, and once installed were practically no trouble. Cylinders, copper-lined, in large sizes, and of copper entirely in small sizes, with packed pistons, were coming largely into use, owing to the smooth and regular working and greatly increased life of the packing.

Electro copper-coated rams for hydraulic presses also possessed great advantages. His firm had had rams covered in this way in use continuously for twenty years, under very severe conditions, and at varying pressures up to 4 tons per square inch. The process was conducted with great care, and the union of the copper with the iron was so perfect that it was impossible for water, under the most severe pressure, to penetrate between them, thus permitting the copper to be worn entirely away without any danger of its being detached from the iron. This valuable property admits of a great economy in the use of copper, as there was no necessity for any greater thickness than $\frac{1}{32}$nd of an inch. This copper was very close and dense, possessed great tenacity and toughness, and was free from defects or porosity qualities, which could not be obtained by cast metals, such as iron, brass, gun-metal, etc. This system of electro-coppering was also largely in use for engraving purposes, for which an absolute perfection of surface is required. As showing the effect on the life of the leathers, one user stated that he had had a copper-coated ram working for nearly nine years *with the same leather*, and another user that the average life was

over five years per leather, and the saving since the coppering was done £10 per annum per press for leathers alone.

With regard to gun-metal bearings, of which Mr. Storey had given some proportions, if they wanted a mixture that would last, he would advise them to try—86% copper, 12% tin, and 2% zinc. They would find it rather difficult to machine, otherwise their troubles with bearings would be very much at an end.

Mr. JAMES VOSE, speaking of competition, said he found that certain articles supplied by a reputable firm, in gun-metal, and weighing 2lbs. each, cost 2d. each more, as castings, than the same articles in a finished condition were being offered by another firm. How that could be done remained a mystery both to his firm and to many other people.

Mr. CLARK (Broughton Copper Co., Ltd.), at the invitation of the president, ventured to say a few words upon this subject, although he had considerable diffidence, not being an engineer, but a commercial man, engaged all his life in the selling of copper.

Speaking of large tubes, Mr. Storey had remarked that tubes could be got of fairly large diameters. He would supplement that remark by saying, that during the past fortnight his firm had made a seamless copper tube 12ft. long × 18in. diameter × $\frac{7}{16}$in. thick.

Some years ago he (Mr. Clark) took part in a discussion before the Naval Architects in Glasgow, in which they were under the impression that nothing larger than 6in. diameter in seamless copper tubes could be made, and the members were surprised when he (Mr. Clark) referred them to a stand his firm had at the Glasgow Exhibition, so long ago as at that time, where they had tubes 80ft. long × 10in. diameter × $\frac{1}{4}$in. thick, and others of 12in. diameter, but shorter. They could make a tube

as large as 18in. bore, and the members had only to create a demand for something larger and it would be met.

He found himself in rather a serious position, inasmuch as he must differ from Mr. Boswell, but he did so with diffidence. The only reason he would venture to say anything in opposition to Mr. Boswell's remarks was, that some years ago, a discussion took place before one of the engineering institutes, in which statements were made that copper was a thing of the past, so far as main steam tubes were concerned. His firm had taken the trouble to obtain the Board of Trade Returns for that particular year wherein the failures of copper pipes were all stated. He went carefully through them, and analysed them, being interested, of course, mainly in the seamless copper tubes. Mr. Boswell, when contrasting brazed and seamless copper tubes, must remember that seamless copper tubes were now about eight times as largely used as brazed, under ordinary circumstances. That being so, they must naturally expect that there would be rather a larger proportion of seamless tubes than brazed failing, owing to the larger number used. Many of his principal customers would not have brazed tubes in their engines at all; everything was specified seamless, and so he found it to be throughout the country.

He (Mr. Clark) went through the Board of Trade Returns, and spoke to an eminent marine engineer, known probably to most of the members present, who had stated, before the institution in question, that the day of copper pipes was doomed. He pointed out to this gentleman that he (Mr Clark) had analysed the Board of Trade Returns for the year, and found that about 75% of the explosions were accounted for by the Board of Trade engineers on the ground of insufficient allowance for expansion and contraction. That was the very point Mr. Storey made, and Mr. Boswell also admitted in four cases. Insufficient allowance for expansion and contraction, that was to say, the

engineer, in designing those pipes, had not made, what, in the eyes of the Board of Trade, was sufficient allowance for the steam pipes. As a rule, engineers never treated copper with the same gentleness that they treated steel and iron pipes, which latter are provided with expansion joints, &c. In dealing with copper, they did not make the same allowance for expansion, but relied upon the excellent bending qualities of copper. Then when it broke, they said, "Where was the good of the copper pipe; let us have a steel one." The eminent engineer in question said the facts could not be denied, but asked why there was no Copper Institute. On being asked what for, he replied, "So that engineers could get to know what copper would stand, and what it would not stand." He (Mr. Clark) replied, that if they would apply to any first-rate firm, they would have been able to find out what it would stand, or would not. He asked if it was fair to condemn copper, when they had not been giving it a fair trial. He could not go further into the matter now, but he had a very distinct recollection of the incident, and it seemed that Mr. Boswell's figures of later years required a little more analysis.

There was no doubt that the brazing of pipes was a rather serious danger. Dr. Kirk, of Napier's Lansfield Works, went very thoroughly into this question of brazed and seamless tubes, made a number of experiments, and came to the conclusion that seamless tubes were so much more reliable, that it was possible to reduce their thickness as compared with the brazed pipe.

The difficulty of the brazed pipe was not only that the seam was so weak, but also that the effect of the heating of the copper whilst brazing the seam had been rather to weaken the copper a little distance from the seam.

He remembered an experiment, which was very instructive, being shown to him by their works chemist, Dr. Watson, who was a considerable authority on copper. He (Mr. Clark) was speaking

one day of "burnt copper." Dr. Watson remarked that there was no such thing as "burnt copper." Then they went into the works laboratory, where Dr. Watson took a short piece of iron pipe, 1in. diameter, and 8in. or 10in. long. He then bored a hole through a cork, and pushed it into the middle of the iron pipe. Then taking a strip of copper, he placed it in the vice, and showed that it would bend any way. Dr. Watson then placed the piece of copper in one end of the iron pipe, filled the other end with coke, and corked the pipe up at this latter end. He then held the tube containing the coke over a Bunsen burner, so that the coke was heated, and the gas from the coke passed over the piece of copper. After a few minutes he took the piece of copper out, placed it in the vice again, and it broke off quite short. The copper had been "gassed." There was no flame, nor possibility of burning it, It was a pure case of "gassing," and was due to the carbon monoxide from the coke absorbing the oxygen in the copper as it passed over the latter, thus leaving it brittle.

To avoid this question of brazing in the case of main steam-pipes, some years ago his firm devised a class of pipe which they thought would have met all the difficulties. It was a pipe with the end tapered—that is to say, if the body of the pipe was, say $\frac{1}{8}$in. thick, it gradually tapered up to $\frac{1}{4}$in, thick at each end, for about 1ft. from the end, the theory being that this thicker part could be flanged upon itself, and would be strong where failures usually occur. Two steel flanges bolted together would, of course, hold the flanged copper surfaces together. This pleased certain customers, and worked satisfactorily. The marine engineer, however, did not like them, because he could not always say the exact length of pipe he required. But in the case of a steel or iron pipe, they had to be very exact, whereas with a copper pipe, it was easy to cut an inch or two off the length, and that was one of the advantages of copper.

Some years ago he (Mr. Clark) made a trip to America, and while there went through one of the largest copper and brass-tube works. He found that the manufacture of copper tubes there was about 50 years behind this country, and in a return visit by the manager of one of those American works to the Broughton Copper Works, the manager admitted they were behind us in the initial processes of manufacture of copper tubes—that is, in dealing with copper in the casting under pressure and subsequent hydraulic forging. These two processes enabled them to produce copper piping free from blow-holes and laminations.

Mention had been made of the value of the old copper. It was amusing that in cases where there had been a sudden jump in the market price, calico printers, for instance, had obtained more for their old copper rollers than they actually paid for them new. They could not say the same for steel, As an investment for the future generation, it was therefore a good thing to go in for copper. The subject was of great interest to him personally, and he could spend a considerable time in expatiating upon the virtues of copper. Needless to say, he was a thorough believer in it. After 25 years' experience, he did not feel ashamed of it, nor of the class of material produced by his firm, and in spite of the talk of using steel for main steam-pipes, they were still making copper pipes in sizes ranging up to 12in. diameter, for copper-steam pipes, and have large numbers of customers who will use nothing else,

The PRESIDENT (Mr. E. G. Constantine), in closing the discussion, said copper had always had a fascination for him, because the manipulation of it was one of the finest handicrafts they had, and he thought the working of copper came next to iron and steel. He did not agree with the expert chemist mentioned, that copper cannot be "burnt," because the first experience he

had in attempting to braze a lubricator pipe of a locomotive, (which passed through the smoke-box), was that not only was the copper burnt, but that it disappeared altogether in the fire.

There were a number of important points in the paper, but time precluded their discussion.

A distinction had been drawn by the author, and emphasised by Mr. Whitehead, between the injury occurring from gassing as apart from overheating. That was a very important point; and the danger also of imperfectly brazed tubes was one that had been emphasised in many instances.

He was surprised to hear Mr. Boswell's views with regard to the failure of steam-pipes, as mentioned in the Board of Trade Reports. He (the President) saw these reports also Some years ago he investigated closely the subject of copper steam-pipe explosions, and the conclusion he arrived at, after careful analysis of the failures in copper pipes, was, that it was not due to the metal, but was due to three causes—either imperfect brazing, bad design of pipes, or deterioration of the metal from overheating by highly super-heated steam, due to failure of water in the boilers causing the upper tubes and combustive crowns to become red hot, Those were the three principal causes of failure of copper steam-pipes, and he was sure that anyone who read the Board of Trade Reports, and saw the reasons why some of the main steam-pipes ruptured, would come to the conclusion that it was surprising they had not fractured before.

He was glad to hear the remarks of Mr. Prout. He had apparently been a sea-going engineer too, and would be able to corroborate the statement that the vibration of engines amounted in some instances to as much as from ½in. to 1in. fore and aft, or midships, during heavy weather. That threw heavy strains on the flanges of steam-pipes, and any material that would

stand that, copper or otherwise, must be a very good material to endure such "punishment" for any lengthened period.

He regarded, also, the instructions Mr. Storey gave to designers, with regard to radius, as most valuable.

With regard to brazing, he thought more failures had occurred in the joints of steam-pipes, not from the difficulty in brazing altogether, but from the fact that in bent pipes the laps had not been properly kept together. If the laps moved a little at the scarfing, the metal became thinner than the body of the pipe.

Before asking Mr. Storey to reply briefly to the discussion, he wished the members to show their hearty appreciation of the paper by passing, with acclamation, a hearty vote of thanks to him for his paper.

The vote of thanks was passed by acclamation.

Mr. W. E. Storey, in reply, said it had been a pleasure to him to listen to the criticism passed, and he hoped that the ventilation of the subject would be of service, both to the people who use copper, and to the people who have the opportunity of supplying it.

Time was limited, and he could not reply to all the points, but would reply to the most important of them.

Mr. Boswell very rightly ascribed a great deal of the difficulty experienced in copper to bad workmanship, which often had its origin in keen cutting competition. He had been told recently of contracts for copper pipes for steamship purposes being placed at a price only just exceeding the actual cost of the copper to the coppersmith by about 2½d. to 3d. per lb. He maintained that it was absolutely impossible to do good work at those prices, and so long as the practice of cutting prices was followed by engineers, so long would that trouble occur. Mr. Boswell had slightly misunderstood his use of the word "fatigue." He (Mr Storey) was thinking more of expansion and contraction strains,

which were constantly acting on the pipe, when it was used as an expansion joint, just behind the flanges. The metal, under such conditions, in time became crystalline. This change was less rapid in copper than in steel, because the former was so much more ductile. Annealing would restore the pipes to their original ductility, and prevent the breaking off of the flanges, which was so frequent a cause of trouble. In the case of steam hammers, there should always be a loop in the steam-pipe to take up the vibration.

The risk of brazing was alluded to in the paper. That was one of the drawbacks of the trade of the coppersmith, but if time and skill and careful supervision were given to the operation, he did not think the risks were greater than those of other engineering practice.

Mr. Boswell objected, in the first instance, to the brazing as being very risky, and then went on immediately to state that he preferred the brazed to solid drawn pipes. He (Mr. Storey) did not quite follow his argument in this.

With regard to the use of copper for steam-pipes, he did not advocate its exclusive use for steam ranges, but he did suggest that it could, with advantage, be used for expansion bends, corner bends, and making-up pipes, and in these the economy of labour came in. If he could prove to them that copper was suitable, and that they ran no risk by employing it for such purposes as described, whilst certain advantages were to be secured by its adoption, engineers would be blind to their own interests if they continued to refuse to employ it for those purposes.

When speaking of the Board of Trade Reports on failures of steam-pipes, he referred to a previous paper he had written. He said, at "that time," the analysis of the report gave almost the result stated by Mr. Clark. In about 75% of the cases

failure was due to inadequate provision for expansion and contraction.

That bad design had much to do with failures had been proved in his experience by many examples.

There was a case on one of an important line of steamships where they had an expansion joint of the stuffing-box type in the main steam-pipe leading from the boiler to the engine, directly coupled to this was a copper right-angle bend, one end of which went into the stuffing-box, and the other led on to the engine.

It was not necessary for one to be a consulting engineer to recognise the absolute uselessness of such an expansion arrangement, and to predict, what frequently happened, the breakage of this bend behind the flange, where it was rigidly fixed. That pipe was put in by one of the leading ship-building firms in this country. So long as this class of design is followed, failures will occur, and they will doubtless continue to be ascribed to the employment of copper.

His firm was the victim of a similar case on one occasion, in which a set of electrical engines had just been put up. The main steam-pipe range was of iron, and the corner bends were of copper. On the day of the accident, the man at the steam-valve on the boiler had slightly opened it some little time before the engines were started, thus causing a great amount of condensation. The condensed steam was supposed to be collected in a sump, drained by steam traps. When the stop-valve on the engine was opened, there was a plug of solid water carried along the pipe to the first copper bend. This pipe was driven out of its flanges, and one of the attendants was injured.

On examination afterwards, it was found that the steam-traps were all choked up with cotton-waste and refuse. He maintained that was not a case against the copper pipe; it was simply a case where the weakest pipe was bound to give way. The situations in which pipes had often to be placed were frequently so con-

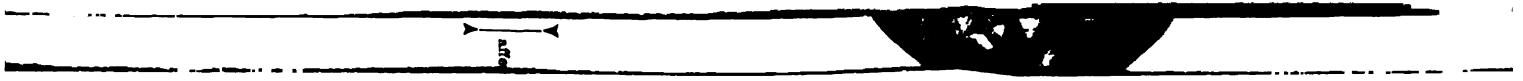
tracted and cramped that pipes of steel having sufficient flexibility could not be constructed. He knew of instances in which it had been necessary, for this reason, to replace a steel pipe with a copper one, with perfectly satisfactory results.

Mr. Prout had spoken about wire-binding of copper pipes. That was done under the Admiralty specification under a definite tension. There were generally three of these wires spaced equally round and brazed, with special connections to the flange. They are then wound, with definite weights attached to the wires. He did not think it would be safe to consider that the winding added any appreciable strength to the pipe. He agreed with Mr. Prout's view in this.

With regard to brazed and solid drawn tubes, the test on which he placed the greatest reliance was the test of using the pipes in a coppersmith's shop. In 99 out of 100 failures in the shop in bending, brazed pipes were responsible, therefore he preferred solid drawn tubes.

He thanked Mr. Whitehead for the interesting series of microphotographs he had shown round to supplement the illustrations in the paper.

1 Plate follows illustrating this Paper.



TOPICAL DISCUSSION.

SATURDAY, DECEMBER 12TH, 1903,

INTRODUCED BY

Mr. JOS. BUTTERWORTH,

MANCHESTER.

STEAM TRAPS.

In opening the discussion on steam-traps, Mr. BUTTERWORTH said: I shall not try to prove that any particular trap is first and the rest indifferent, but shall endeavour to examine the various types of traps as to how they perform their work under suitable conditions. Not many months ago one of our members made the sweeping statement that there was not a good trap in the market. The fact is that the average engineer will not take the trouble to understand the conditions under which a trap has to work. It is usually deemed sufficient to connect the trap to the lowest part of a pipe-range or receiver, connect the outlet to some handy drain, and if anything goes wrong—the trap is deemed a fraud. If water gets into the cylinder, it is evident the trap is no good; no allowance is made for the fact that steam rushing through the pipes with the speed of a hurricane carries the water forward in the form of spray. Or maybe the trap is blowing steam. Again the trap is blamed, although it may have to deal with solids precipitated from the water during boiling, sand from the interior of the pipes, rubber or other jointing matter, or, in fact, anything heavier than water which naturally gravitates to the lowest point, to which the trap is usually fixed—things which no trap can be expected to pass without getting damaged or out of order. But perhaps the most

neglected fact in connection with the trapping of water from steam is that water cannot remain in the liquid form at atmospheric pressure if over 218° Fah.

When it is considered that even at 20lbs. pressure the temperature of steam is 260°, and at high pressure, say 200lbs. per square inch, the temperature is 387°, it must be evident that if the trap is taking all the water out of the pipe or receiver, the water, having been in contact with the steam, must be at something near the same temperature.

This means that some of the water must re-evaporate when liberated into the atmosphere. The latent heat absorbed in forming such vapour, cooling the remainder of the water down to 212° Fah. This is an elementary fact that would be appreciated by any youth attending the engineering classes at our Technical Schools, and yet the greatest difficulty is often experienced in getting steam-users to appreciate it. What is required is a trap that will perform miracles.

It must go into the pipes and cylinders and extract the water from the steam previous to draining it off. It must be able to pass any sort of solid material, from a half-inch nut downwards, and it must be able to upset the laws of nature by passing water at 3 to 400° Fah. into the air without emitting steam. Having said so much as to the onerous nature of the duties of a steam-trap, let us examine the various types used.

The earliest type consisted of inverted ball-taps of various shapes and arrangements—some direct-acting, others in which the float had a considerable leverage over the valve, but in all cases the accumulation of water in a chamber served to raise the float and open the valve, the escape of water lowering the float to close the valve. Traps of this type are much used on the Continent and in the United States, and if given fair treatment will do their work well, but owing to their having to be made to withstand the full steam-pressure, they are usually heavy and

costly, while the copious discharge of re-evaporated steam prejudices most users against tham.

The next type to be used was the expansion trap, which was introduced in workable form by Vaughan in this country and by Kusenberg in Germany, other modifications being afterwards made by Lancaster and by Royle. They all utilised the difference in expansion of two metals, such as brass and iron, to operate a valve and discharge the water. About the same time traps were introduced in which liquid, having a lower boiling point than water, was used in a vessel having elastic sides, the pressure generated in the volatile liquid by the escaping hot water or steam being utilised to close the valve. Later, the same principle was used in combination with a Bourdon tube for the same purpose.

The next type of trap to be introduced was of the float type, but had the valve controlling the discharge of water placed at the inlet to the trap, so that by having the outlet from the trap large enough little or no pressure was exerted in the trap itself. Most of the float traps at present in use are of this type, such as the Robinson, the Royle, and the Lancaster traps. They have many advantages, such as lightness, simplicity, and cheapness, compared with the old float traps. Also, owing to the working parts not being under steam pressure, they are more durable and certain in their action. In the Robinson, Lancaster, and numerous similar traps since invented, the action is similar to that of an automatic weighing-machine, as the water, after passing the valve, passes through a tubular lever into and through the float into the trap. Thus the escaping water partially fills the float, causing it to open the valve full, while immediately steam appears it drives the water out of the ball, causing it to float and close the valve. The opening and closing of the valve thus depends on the weight of water in the float.

It will be apparent from the foregoing description that the normal position of the trap when steam is off is full open; also,

any derangement of the working parts would leave it in the same position, whereas in most other float traps the reverse is the case, which in my opinion is an element of danger, as the mechanism is always liable to get stuck while standing, especially if dirty water is passed by the trap, and it is surely better to stick open than shut, so that attention is at once called to the fact by an escape of steam, instead of attention to the fact being more forcibly arrested by an expensive smash of mechanism, &c. Also the escaping water and steam may remove the obstruction and automatically set the trap to work again.

They also have the advantage that the trap will work equally well with the cover removed, so that they can always be examined. Returning once more to the expansion traps, there is no doubt that they have latterly been more in use than when first introduced. There is no difference in the principle on which they work, compared with the old traps, but better workmanship and a more intelligent distribution of the metal to withstand the immense strains they have to meet has rendered them more successful than formerly. Their chief advantages are the small space occupied and the ease with which the outlet, being small, can be connected to a drain, where, if any steam escapes, it is at any rate out of sight.

Their disadvantages are the infinitesimal movement of the valve at the range of temperature which takes place when the plant is under steam, and the great strain thrown on the material of the trap by the leverage introduced to increase the lift of the valve. The expansion of brass or copper is less than $\frac{1}{30000}$ part of its length per degree Fahrenheit, so that the leverage introduced between the operating tube and the valve has to be enormous to get any appreciable opening. I notice that one well-known trap puts the leverage down at 100 to 1, *i.e.*, the motion due to expansion is magnified 100 times.

Now, if we take the sectional area of the metal forming the tube to be equal to the area of the valve which has to be opened or shut against steam pressure at, say 200lbs. per square inch, the stress on the metal must be 200 × 100, or 20,000lbs. per square inch, a manifestly impossible working stress for brass, or even steel, so that the maker must have over-estimated the extent of his leverage, or his trap would have smashed. There is no doubt, however, that the metal tube does gradually give in practice, and the traps have to be re-set at intervals to prevent escape of steam. The small opening of the valve is also conducive to the scoring of both valve and seat if the least grit is present in the water.

Mr. Sam Boswell said he was present to defend the statement he had made on the occasion when Mr. Stromeyer read his paper on main steam-ranges. He still said there was not a reliable steam-trap on the market for main steam-pipe installations, and if he required proof of this statement, he had only to refer to the opening of the topical discussion by Mr. Butterworth.

He did not expect a steam-trap to pass half-inch nuts, but when firms advertised and put upon the market a guaranteed automatic steam-trap, he did not expect that trap to require examining every week-end. At the same time, he did not expect to find himself in the midst of a London fog when going through the engine-house where one of these so-called reliable appliances was fixed. He had nothing against the steam-trap, but it had been most unfortunate for him to have to do with a number of accidents which had occurred through the steam-trap having gone wrong. The engineer did not know why the trap had gone wrong—it had never gone wrong before; but it had gone wrong, and therefore, if it went wrong, it was not reliable.

The members would remember on the particular night when he last mentioned this matter, Mr. Michael Longridge came late,

and in his remarks told them that the only case where a wrought-iron or steel steam-pipe had burst was where water had accumulated through something going wrong with the steam-trap. On that occasion there was laughter throughout the room, and Mr. Longridge did not know the cause until after the meeting.

He still maintained that for main ranges they were not reliable. He spoke from experience, not because he had any interest in offering something else for sale, or doing without them; but he thought it was possible, with a proper arrangement of the steam-pipes and boilers for large engines, to work with less loss and more reliability without them. It only required a man with common sense, and there would be no loss. It was simply a question of pipes being open; it was not a question of passing a valve at all. He believed it was more reliable to have an open pipe with a tap, than a steam-trap.

After the meeting in which he made that remark, he met Mr. Stromeyer, the author of the paper on "Water-action, and the accumulation of water in pipes," when he (Mr. Boswell) said he could devise an arrangement which, so far as boilers were concerned, would do away with steam-traps, and they could arrange their pipes in any way they thought fit.

Mr. Butterworth makes a very wise provision, that it "was better to arrange the trap so that it would blow, rather than not blow at all." There was no relief in that. He did not require a trap to work miracles; he merely required it to do what Mr. Butterworth says it will do, and there was no miracle in that. In boiler plants he confined himself to this, that they had yet to give the trade a reliable trap. The most effective way of draining pipes he had known was at a cotton mill, where all the drains were open pipes, with a gradual fall to the inlet side of a superheater. He wished it to be understood his remarks had no reference to steam-traps connected to calenders and such like, as

that was not his branch of engineering, though he had heard unpleasant things said about them in that section of the trade,

Mr. GEORGE SAXON thought justice might not be quite done to the steam-traps if Mr. Boswell's remarks were left unanswered. It seemed to be considered by the engineering world that steam-traps were a necessity, and that the old-fashioned method suggested by Mr. Boswell was not in harmony with present engineering practice. It appeared to him that there was some force in the argument laid down by Mr. Boswell that the steam-trap, being so sensitive an instrument as it necessarily must be to perform its function properly, if it did not receive proper attention, or be fixed properly, it would refuse to do its work effectively, and an explosion or burst pipe would be the consequence, or some other equally disagreeable feature result.

If they had a delicate mechanical instrument or something that was very sensitive, of a necessity it must require attention from time to time, and to his mind the difficulties with steam-traps had been largely with the attendants, who had been under the impression that when once a steam-trap was put down and fixed, it required no more attention until it wore out, or until a steam-pipe bursted, indicating that the steam-trap was blocked up or stopped. Therefore, that pointed out the fact that steam-traps were good enough in their way, and although they might have different qualities, he was not going to say which trap he considered the best; there were so many on the market. He considered, in regard to these steam-traps, that justice ought to be done to them in their having the requisite attention to keep them in perfect order, and to keep them doing their proper function, and then very great advantages would be derived from them, without either damage or difficulty.

Mr. E. MARSHALL could not quite agree with Mr. Boswell's statements. He personally had tried steam-traps all round, and

found the general fault was that they were left to chance, which should not be the case. There was a simple way of getting over the difficulties, and that was to make a box to arrest all foreign matter which gets into the pipes—one easy of access. His surprise was that trap-makers do not embody this in their traps. He had adopted it in their own plant, and it had worked well. It was simply a vessel about 6in. diameter, 3in. deep, with a plate in the middle. This was perforated with small holes. If it was made large enough, it did not require so much attention. Shut the tap attached to the trap, take off the cover of the vessel occasionally and remove what foreign matter is there, and they would then have no trouble. They had traps working that could not be worked by a man, with an open pipe and tap, on account of the variations. Sometimes the steam was going through at full force, and at other times it was just trickling through. There it would be disastrous to risk with a man working a tap. Take a drying-machine, with a large number of cylinders. In this case a man could not work an open pipe with a tap, as mentioned by Mr. Boswell; but with an automatic trap, well looked after, they did not require to do anything of the kind.

The PRESIDENT (Mr. Constantine) said he was a strong believer in steam-traps. Whether they were for draining steam-pipes, or for draining cylinders, or any sort of vessel in which condensation of steam takes place. Even the best designed steam-trap would be ineffective if it did not receive proper attention. There was no question in his mind that a great deal of the trouble was due to the fact that in many cases the traps were put in out-of-the-way corners, out of sight. They were there, and were expected to do their work for years without being looked at. He had that week been through one of the largest electricity generating stations for lighting purposes, and there was not a single trap which was not fully exposed for inspection.

They could see whether the trap was working or not. He thought no question could be entertained that steam-traps were far preferable to any ordinary tap, to open or close.

The wastefulness of taps, if they were left open, was often enormous. If they were not left open, they did not let the water out. Well designed steam-traps, whether of the float or expansion types, are suitable for certain purposes, and they should be placed in that particular position in which they are most suitable. If properly looked after, they were a most valuable servant.

He asked Mr. Butterworth to reply to the discussion.

Mr. BUTTERWORTH, in reply, said he did not think Mr. Boswell met his remarks quite fairly, because he merely reiterated what he said before without trying to dispel any of his (Mr. Butterworth's) arguments. As mentioned by a number of the speakers, a large amount of the trouble was caused owing to the traps not being intelligently used, and engineers not taking the trouble to attend to them. There was as much sense in talking about doing without the trap, and having a pipe and tap, as trying to do without safety-valves and water-gauges on boilers.

Mr. Saxon also mentioned the traps require examining. In 14 years' experience he could mention some curious incidents with respect to the examination of traps. He had been to a place where there were several working, and in one case noticed a drain-pipe coming from the engine and entering the ground. He spoke to the engineer in charge about this, who said he did not know where it went to, but he supposed it was connected to one of the traps. They got a spade and dug to the trap, which was buried two or three feet deep in the ground. It had been there for 14 years, and was working perfectly. There were cases where the water was clean, or means taken to exclude dirt or adjoining material that might get to the trap, and in such cases

the traps worked all right, as mentioned above. If designed with no undue strain on any of its parts, and mechanically simple, there was no reason why a steam-trap should not work as well as any engine, boiler, or other mechanical arrangement.

With regard to supplying a separator with the steam-trap, that was practically a separate machine, and was supplied by most makers, and generally described in the catalogue as such. They might not all be in the same form, still it was an appliance which answered the same purpose. He might speak from experience, that where the water was very dirty, and the impurities were of a very fine state, there was no form of separator known that would entirely eliminate the dirt. They would find it got into the trap and caused obstruction at times. It was impossible for any separator to keep all the dirt out.

With respect to Mr. Constantine's remarks, his experience was identical. Some traps did better for certain classes of work than others.

He thanked the members for their discussion.

48TH Annual Report

OF THE COUNCIL,

1903.

MANCHESTER
HERALD & WALKER, POOL FOLD CHAMBERS, OFF CHAPEL WALKS.
1904.

COUNCIL.

1904

President:

MR. ALFRED SAXON.

Vice-President:

MR. E. G. CONSTANTINE.

Treasurer:

Trustees:

MR. T. ASHBURY	MR. J. WEST
SIR W. H. BAILEY	,, HENRY WEBB
MR. J. NASMITH.	

MR. G. KIERNAN	MR. L. F. MASSEY
,, R. MATTHEWS	,, S. BOSWELL
,, W. TAYLOR	,, J. J. ROYLE
,, A. WALSH	,, T. ROBERTS
,, J. ATKINSON.	,, W. INGHAM

Librarian:

MR. R. GASS.

45, High Bank, Gorton.

Secretary:

Mr. FRANK HAZELTON.

29, Brown Street, Manchester.

ANNUAL REPORT OF COUNCIL,

1903.

The Council have pleasure in presenting the 48th Annual Report of Proceedings.

To the membership roll during the year have been added—

36 Members,

and after taking into account the loss by death, resignation, and erasure, the total number of names of all classes on the roll amounts to 530, as against 515 in the previous year, namely :—

25 Honorary Life Members.
254 Members.
251 Members (entitled to Financial Benefit according to Rule 7.)

Total 530

Upon reference to the Financial Statement, as certified by the auditors, it will be seen that the balance standing to the credit of the Association, after payment of all accounts due up to the 31st December, amounts to £5,590. 2s. 10d., as against £5,404. 4s. 4d., at the close of the preceding year, thus showing a surplus of £185. 18s. 6d. on the year's working.

SUPERANNUATION FUND.—

There are at present seven superannuants, each receiving a weekly allowance of 8/-.

It is with profound regret the Council have to record that during the year death has removed the following Members, prominent amongst them being the late Treasurer, Mr. James

Walthew, who for many years laboured earnestly and unremittingly in the interests of the Association.

Bates, Henry - - - -	Manchester.
Mercer, Ed. - - - -	Hollinwood.
O'Connor, Chas. - - . -	Liverpool.
Parker, Thos. - - - -	Gorton.
Swain, Matthew - - - -	Manchester.
Walthew, Jas. - - - -	Do.

The following gentlemen have resigned their membership during the year:—

Bond, J. T. - - - -	Stockport.
Goodfellow, G. B. - - -	Hyde.
Hampson, R. S. - - - -	Sheffield.
Heywood, Brookes - - -	Manchester.
Redfearn, W. R. - - -	Chesterfield.
Wilson, J. - - - -	Glasgow.
Windeler, G. E. - - - -	Do.

The following gentlemen have ceased to be members during the year:—

Browett, T. - - - - -	London.
Clarke, Richard - - - -	Manchester.
Heaton, J. S. - - - -	Do.
Hyde, J. B. - - - -	Do.
Hodgson, Percy - - - -	Do.
Robson, P. W. - - - -	Do.
Gregory, G. W. - - - -	Do.
Whiteford, T. H. - - -	Do.

During the year, in addition to the ordinary meetings, the following Excursions and Social Gatherings have taken place, brief accounts of which are included herewith:—

Feb. 14.—Anniversary Dinner. Attendance 163.

Apl. 25.—Inspection of the Municipal School of Technology. Attendance 200.

June 22.—Visit to Coventry; inspection of the following Works: Messrs. Alfred Herbert, Limited; The Daimler Motor Co.; The Motor Manufacturing Co. Attendance 70.

July 18.—Visit to Chester, Eaton Hall and Hawarden. Attendance 60.

Oct. 10.—Inspection of Messrs. Craven Bros.' Works, Reddish. Attendance 200.

TOOL STEEL EXPERIMENTS.

The Council have pleasure in reporting that the Joint Committee have practically completed their experiments on tool steel for high speed cutting, the Report of which was presented at the October Meeting. It is hoped shortly to issue the Report and Discussion in pamphlet form to the members, that it may be convenient for reference to those interested.

PRESIDENT'S GOLD MEDAL FUND

The most desirable way of carrying out the object of the generous gift of the President, Mr. Constantine, has had the attention of the Council, and it is anticipated that during the coming year an acceptable scheme will be laid before the Association for consideration.

PAPERS READ AND DISCUSSIONS HELD DURING THE YEAR.

Jan. 17.—"Inaugural Address" by the President, Mr. E. G. Constantine.

,, 31.—"Steam Turbines," by Mr. R. M. Neilson, Manchester.

Feb. 28.—"Gas Engines, with recent developments," by Mr. Jas. Atkinson, Manchester.

Mar. 14.—"Pneumatic Tools," by Mr. E. C. Amos, London.

,, 28.—"The Premium System of Remuneration in Engineering Works," by Mr. John Ashford, Manchester.

Apl. 25.—"Equipment of the Mechanical Engineering Laboratory of the Municipal School of Technology," by J. T. Nicolson, D.Sc.

Oct. 24.—"Report on Tool Steel Experiments carried out at the Manchester School of Technology," read by Dr. J. T. Nicholson, on behalf of the Joint Committee.

Nov. 7.—Discussion on "Tool Steel Experiments."

Nov. 14.—"Speeds of Machine Tools," with special reference to the proportions of Pulleys and Gearing, by Mr. P. V. Vernon, Coventry.

Nov. 28.—"Condensing Plant for High Vacuums, with limited water supply," by Mr. W. H. Roy, Manchester.

Dec. 5.—"The Application of Copper to Engineering Practice," by Mr. W. Ed. Storey, Manchester.

Dec. 12.—"Steam Traps." Topical Discussion introduced by Mr. J. Butterworth. Manchester.

The Council, in conclusion, desire again to express their appreciation of the assistance given by those members and friends who have read papers, contributed to the discussions, or otherwise co-operated in the work of the Association during the year.

ANNIVERSARY DINNER.

The Forty-sixth Anniversary Dinner was held on Saturday evening, February 14th, at the Grand Hotel, Aytoun Street, under the presidency of Mr. E. G. Constantine (President of the Association). The company numbered upwards of 160. The guests included Sir James Hoy, Mr. W. J. Crossley, Dr. A. Hopkinson (Principal of Owens College), Mr. H. S. Loud (Westinghouse Company), Mr. J. H. Reynolds (Principal of the Manchester School of Technology) and others.

Mr. J. Nasmith proposed the toast of "Municipal and Educational Institutions." He said it was one of the most gratifying things in English life that the municipalities were taking upon

them more and more of the work of the community, with that full knowledge of local interests which was not possessed by the House of Commons. Those who were willing to engage in the work of the municipalities deserved our warmest thanks. They were not infallible any more than engineers were infallible, and it was perhaps a thing to be remembered with some humility that when a municipality made a mistake it was generally after having had the advice of an engineer.—(Laughter.)

The troubles that were possessing Manchester and Salford to-day were troubles with regard to electricity and the disposal of sewage, and in both of those matters they had sought the advice of engineers without entirely getting themselves out of the mess. If we would get a perfect municipality we must have a perfect citizenship, and we were a very long way from that.

The municipality had added to its many duties the duty of taking charge of education. There were some who thought the burden would be too heavy for them. His experience, however, led him to believe that the Act would be administered with that fairness and regard for justice which had always characterised the administration of any Act by any wise municipality. The presence of a University in a large city was an unmixed good. He rejoiced to see the union which was taking place in Manchester between the educational and the municipal authorities. That union would not be close enough until it included in it a university.—(Hear, hear.)

Sir J. Hoy, who responded, said he did not know anything that a man could do with much more advantage than to try to help on the machinery of local government. Those who were engaged in that work had been put upon their metal by an attempt that had been made to show, first that Manchester borrowed too much money and owed too much money, and secondly that the municipality had no right to interfere with

trade. As to borrowing money, Sir J. Hoy pointed out that though Manchester was credited with owing £19,000,000, yet if they looked at the purposes for which the money was borrowed it would be seen that the pre-eminence of Manchester came from its large view of its duties, not only towards the population of Manchester but of the district that surrounded Manchester.

Of the sum he had named, £5,000,000 was used for the purposes of the Ship Canal, and they knew of what immense value that expenditure on the part of the Corporation had been, not only to Manchester, but to the adjacent portion of Lancashire. A service had thus been done to the public which could not have been done in any other way, and which had repaid itself in advantage to the community over and over again.—(Hear, hear.)

Then another sum, approaching £3,000,000, had been expended upon our water scheme. Upon that the Corporation could make no profit. In regard to it, however, no expenditure had ever been more closely watched or more efficiently administered. Yet the Corporation got little credit for what it had done. Considerably more than one-third of the total indebtedness had come about in regard to the matters he had indicated, and he thought men might very well hold their judgment in suspense and try to understand what were the various liabilities incurred by a city such as that of Manchester.

There had been a cry, emphasised by Sir Edward Clarke and the Lord Chief Justice, for a Royal Commission to inquire into what municipalities were doing. The thing was all nonsense, of course. If it were really called for by any person who had a right to call for it, he was sure municipalities would not shrink from such an inquiry. This demand, he believed, was made by persons interested. It was a capitalist cry, and certain syndicates were really at the bottom of this particular agitation.

The more municipal work was looked into the more would be seen its capacity for dealing with the needs of the people, and the more would the feeling of the public be that attempts to restrict that work were not for one moment to be tolerated. Whatever was wrong could be put right by the municipality itself and the expression of a sound public opinion of a disinterested character. He believed things would never be changed by the action of persons who simply wanted to secure for themselves the opportunity of private aggrandisement.—(Hear, hear.)

Dr. A. HOPKINSON, who also responded, said he believed it had been said sometimes that Manchester was an educational paradise. He did not think it was an educational paradise, but he did say that at the present time he believed it to be the finest educational battlefield that anybody had yet been called upon to occupy. It was the centre of a great, vigorous, active, and earnest population, and it had amongst it a number of people who had made up their minds on the educational question, and who intended that some real progress should be made at the present critical moment. We woke up rather late in England, but when we did wake up we dealt with a matter vigorously and with determination. He desired to say with regard to the education scheme promulgated by Manchester, that it had been drawn up on broad and statesmanlike lines.—(Hear, hear.)

He did not mean to pretend that there was no point on which that scheme could be properly criticised, or that at the proper time people would not venture to criticise it.

"As to university education here," Dr. Hopkinson said, "possibly the opening of Parliament may not be an unsatisfactory and unnatural time when a decision may conceivably be given on that matter which has been interesting not only the

authorities and the members of the Victoria University, but also the citizens of Manchester—and not only Manchester, but the great towns around and their municipal corporations as well—I mean the question of a Manchester University. It may be—it is—conceivable that there will be a decision that we go on as we are; but there may be, on the other hand, and I think those who heard the trial thought that there was a possibility of it, that we shall see in Manchester not only the seat of a federal university, but a university—which will be possibly Victoria University—of which Manchester is the centre, and the destinies of which can be directed by Manchester and the districts which are immediately in connection with it.—(Hear, hear.)

Manchester is the centre of a population of some four millions. I think I shall not be wrong in saying this, that if at first some of us hesitated, and looked doubtfully on the propriety of making this change, yet we felt it was one of importance and of advantage, as well as inevitable. With such a change we can work more closely with the municipal and public life of our own district, we can adapt ourselves more readily to local conditions, we can have a governing body of a wider and more representative character than has hitherto been possible, and we shall be brought more closely into touch with the great educational institutions of Manchester."

Dr. Hopkinson, continuing, pointed to dangers which he said lay in our having too much of insular conceit and unwillingness to recognise and learn from others what they had carried out with success, and with going forward with the idea that there was nothing in the past of England, even in the matter of education, which was worth preserving. There was no cause for despondency, but there was cause for keeping our eyes open and taking advantage of the means of progress wherever they were to be found.—(Applause.)

Mr. R. Matthews proposed "Our Guests."

Mr. J. H. Reynolds, in responding, said a good deal had been said about foreign competition. He was convinced that the successful competition of America and Germany was not based upon any question of tariffs, but upon the question of education. —(Hear, hear.)

The Americans and the Germans had seen the advantage, from a national standpoint, of properly equipping their young people. They had seen, more enlightened than we, where the struggle was to be, and had been preparing their people for it. Huxley saw as clearly as anybody that the real war was not a war between tariffs and artillery, but a war between educated and uneducated nations.

The Technical School had come into existence, with its special equipment, with the intention of training young engineers, and he asked what the engineers were going to do to make it a reality. If they were going to be content that their young men should cease their education at sixteen years of age, and that their cleverest young men should simply get what they could out of evening classes, they might never hope to rival either their American or their German competitor. He appealed to the engineers of the district to afford facilities to the young men in their employ to take advantage of the opportunities provided for them in the School of Technology.

Mr. H. S. Loud also responded. He said the textbooks in technical knowledge which he studied in America were the same as those in use at Owens College. The great works with which he was connected had endeavoured to bring into this locality some of the elements that had meant success in the States. They had at Old Trafford some 75 apprentices from twenty to twenty-two years of age, who came in without

premiums and who began to earn wages at once. They had room for 75 more, and Mr. Reynolds might have them all when he wanted them.—(Hear, hear.)

Mr. W. J. CROSSLEY proposed the toast of "Prosperity to the Association." He said he felt that education was really at the bottom of the matter, and they had been shown how much depended upon it. But if their American friends had made such tremendous strides in that direction, he might ask why it was they kept on a tariff of 48%—(hear, hear)—while we opened the door to them. He warmly endorsed what Mr. Reynolds had said as to the education which was necessary to achieve national commercial success. He asked that manufacturers should stand shoulder to shoulder in the determination that they would not in any way give way to a vice which he felt was creeping into this country—the vice of giving commissions to people interested. If that system obtained a hold on the country it meant decay and rottenness.

Mr. J. WEST and the CHAIRMAN replied.

During the evening an enjoyable musical programme was given by Mr. Ernest Hastings.

REPORT OF EXCURSIONS AND OPENING MEETING OF SESSION.

VISIT TO COVENTRY.

Coventry was visited on Monday, the 22nd June, by the Association. The party numbering 70, left Manchester at 10 a.m., and travelled to Birmingham, thence to Coventry, arriving there just before half-past one. The members were received at the railway station by Messrs. Alfred Herbert, Oscar Harmer, and P. V. Vernon. An adjournment was made to the Railway Hotel, where luncheon was served. Subsequently the members

inspected the engineering works of Alfred Herbert, Limited. Arrangements were also made for visiting the Daimler Motor Company's works, and those of the Motor Manufacturing Company.

Members of the party were supplied with notes regarding each of the works to be visited, and the particular branch of industry carried on there. Representatives of the different firms acted as guides in conducting parties round the works.

At the works of Alfred Herbert, Ltd., the members were interested in the building of machine tools, which in these works was commenced in 1890. The original types of tools produced were of the lighter classes, and were designed more especially with a view to the requirements of the bicycle industry. Since then a steady development has taken place, mainly upon the lines of such machine tools as are used for the production of parts in quantities. The total amount of floor space in the various shops is about 100,000 square feet exclusive of yards. The total number of machine tools was given as 450, and the total number of employees 930. The foundry is at Edgwick, Foleshill Road; it has a total floor area of 30,000 square feet, exclusive of yards, and there are about 160 men employed there. The head works are devoted solely to the production of machine tools, the range of which includes automatic and semi-automatic turret machinery, milling machines, sensitive drilling machines, cutter grinders, &c. After passing through the warehouse and showroom, the members came to the testing department, where all machines ordered with special tool equipment are run and tested upon the actual work for which they are sold before being despatched. Attention was directed to the system of inspection of all finished machines. A staff of inspectors are constantly employed testing and examining machines under erection, and no machine is allowed to leave the works without the inspector's certificate. In the fitting shop it was noticed that this was divided, as far as possible, into sections, with the object of keeping each gang of workmen continually employed upon the same class of work. This enables a higher grade of work to be produced at a low cost. The various other departments of these extensive works were also inspected with evident interest.

Some idea of the progress and development of the motor industry was afforded by the visit to the works of the Motor Manufacturing Co., Ltd., and the Daimler Company, Ltd. With regard to the Motor Manufacturing Co.'s Works, it was explained that the main building consists of four floors, the top floor being occupied entirely with wood-working, viz.: Coach-body

building, car-wheel making, pattern making, and carpentering. The third floor consists of a paint shop, varnish room, upholstering department, and motor erecting department, also the manufacture of a 2¾ H.P. air-cooled bicycle motor. The coach-smiths' work is also done on this floor. Motor cars in all stages of construction were inspected.

Equally interesting to the members were the works of the Daimler Motor Company adjoining. Here it was noticed that the engines and also the various components of the cars were all being produced in large quantities on the strictly repetition principle, thus ensuring absolute interchangeability of all the parts. Numerous cars, both finished and unfinished, were inspected.

The party returned to the Railway Hotel for tea, and following this,

The President proposed a hearty vote of thanks to the heads of the works they had visited and to the staffs. He mentioned the names of Mr. Alfred Herbert and Mr. Harmer of Alfred Herbert, Ltd., Mr. Martin of the Daimler Co., and Mr. Iden of the Motor Manufacturing Co. Although, he said, their visit had been of a hurried character to the works named, it had been a treat. They had had an opportunity of seeing much which interested them.

Mr. Henry Webb, said that at Messrs. Herbert's works nothing pleased him more than to see the shop about four times as large as when he was previously there, a very clear proof that not only were Messrs. Herbert's making tools and machines, but making money. And well they had earned it. (Hear, hear.) Another thing that pleased him was to see some machines, that were old friends of his some years ago, altered and wonderfully improved. That showed Messrs. Herbert's were in the van of progress, they did not think the same patterns should go on for ever. For a long time the engineering trade in England had been charged, he thought unfairly, with taking a wrong tack, and that everything they wanted was made in Germany or America, and that everything made at home was all wrong, and that they were a day behind the fair. Looking round Messrs. Herbert's works, it was clear that this charge was entirely wrong. There were evidences of our English solidarity and the liability of English manufactuers to last for a long time that must have impressed the visitors. (Hear, hear.) He was also pleased to see the number of young men employed so earnestly and so devotedly to their work. He thought they must have been told that the experts of the world were visiting the place—(laughter and applause)—and they must

really be sharp about their work, or these visitors would go away with a wrong impression. The only thing he was disappointed with was that Messrs. Herbert's had put their shop in the wrong place; he thought they should have put it nearer to the centre of the earth. (Laughter and applause.) Of course, those who came from Manchester knew where that was. (Renewed laughter and applause.) As regarded the motor works he was deeply impressed with the quality of work about the motor cars. In both motor works he was very pleased indeed. But what would Messrs. Herbert's tools be, and what would these motor cars be, if they had not somebody to send them some right good steel. (Applause.)

The thanks were demonstratively expressed, and

Mr. Alfred Herbert, responding, assured the members they were under no obligation to his firm; in fact it was quite the other way. He regarded it as a sincere compliment for them to come from Manchester to see "our little shop." He extended an invitation to any of the members to visit the works individually, and assured them they would receive every attention. He wished the party a safe return home and a successful year's work. (Applause.)

M. Harmer also responded, and said his only regret was that the time was so short for their visit.

Mr. Iden would also have liked the visitors to have had more time at their disposal to devote to the motor industry, which was practically a new industry, and see the progress that had been made during the last few years. He should be very glad to remove any impressions as to being afraid of using a motor car, and commented upon the value of motoring from a health point of view. He would be very pleased to demonstrate what motor cars would do, from a small motor car coming within the reach of any individual, to the larger motor cars they made for millionaires. There was no difficulty in the motor, there was no mystery about it. He remarked upon the trouble there had been to get engineers to take up the motor industry, and instanced the difficulty he had four years ago in obtaining an assistant engineer. He pointed out that the increase of the motor industry would mean benefit all round.

The members shortly afterwards returned to Manchester.

VISIT TO CHESTER.

On Saturday, the 18th July, a pleasant excursion of the members and their lady friends was made to Chester, the attendance being 60. The party left Manchester in special saloons in the morning, and on arrival at

Chester dinner was served at the Pied Bull Hotel. Afterwards they were conveyed to Eaton Hall, the residence of the Duke of Westminster, which was inspected with considerable interest by all present.

Subsequently a large number proceeded to Hawarden, this portion of the journey being exceedingly pleasant, as special permission had been given for the drive to be taken *via* the Belgrave and Bretton approaches to Hawarden.

On arrival at the interesting village which has so long been associated with the late Mr. Gladstone, the party inspected Hawarden Church, St. Deinol's Library, and many other interesting mementos appertaining to the village.

Subsequently the party returned to Chester, where tea was served, finally returning to Manchester after a pleasant day's excursion.

VISIT TO CRAVEN BROS. NEW WORKS AT REDDISH.

The Members opened their winter session on Saturday, October 10th, by a visit to the new works erected at Reddish by Messrs. Craven Bros. Limited, of Manchester. These works cover an area of about five acres, and have been specially designed for building Messrs. Craven Bros.' well-known overhead electric and other types of cranes. It is, however, the intention of the firm, who have purchased 20 acres of land, to eventually remove their works from Manchester, where their machine-tool trade is carried on, to Reddish, when the entire works, which will then be concentrated, and the whole of their operations carried out on the one site, will cover an area of 10 acres, the remainder of the land being set apart for the erection of workmen's dwellings, The shops already erected, and which give employment to between 500 and 600 men, are lofty and well-lighted buildings, 25ft. to the crane levels and 34ft. to the square, consist of an extensive foundry, elegantly designed power house, erecting and girder shops, smithy, and special tool department. The foundry is 300ft. long by 125ft. wide, divided into two bays of 50ft., with one side annexe of 25ft. The principal bay is traversed by two 23 ton four-motor electric cranes, the other by two 10 ton three-motor cranes of high speed, modern design, and built by the firm. In addition to the cranes, the whole of the foundry is fitted with pneumatic pipes for working numerous air hoists about the foundry, which can be removed from one position to another as occasion requires. The core stoves attached to the foundry are of large dimensions, one being 25ft. square, with two others 25ft. by 12ft. 6in., and they are all heated by producer gas. One end of the annexe is set apart as

a brass foundry, which is a commodius shop 75ft. long by 25ft. wide. For serving the foundries there are three cupolas, two of 5ft. and the other 4ft. in diameter, blown by an electrically-driven Root's blower. The erecting shop is 325ft. long by 175ft. wide, divided into three bays, each 50ft. wide, and on one side there is an annexe of 25ft. One of the bays is traversed by a 25 ton four-motor electric crane, and the middle bay by a 15 ton three-motor electric crane, with a 10 ton crane running underneath on a separate gantry, which is used independently for serving the machine tools. The next bay forms the girder department, and this is traversed by a 5 ton three-motor express-speed overhead electric crane, which is used for conveying material to the smithy, situate at one end of this shop. The whole of the works are exceedingly well heated and ventilated, and electrically lighted and driven throughout, the bulk of the tools being grouped together, with one or two special tools in the girder department, consisting of plate straightening and bending rolls, punching and shearing machines, and metal saws driven direct by motors attached.

The power for the whole of the works is generated in a separately built power house, which is at present equipped with one 200 kilowatt generating condensing set, consisting of a Belliss and Morcom triple expansion engine, coupled direct to a generator of 200 kilowatt capacity, the condensing plant being conveniently placed in the basement of the power house. The boiler house, which is alongside is fitted with a Lancashire type of boiler, 30ft. long by 7ft. 6in. diameter, built by Messrs. Musgrave & Sons, Bolton, and the steam is generated at 180lb. pressure. It may be mentioned that the power house has been built of sufficient dimensions for trebling the present generating plant, and the adjoining boiler house has also been constructed so that the steam power can be increased to a proportionate extent. Adjoining the works are the offices, which, although at present temporary structures pending the completion of the entire work, are commodious and well equipped providing ample accommodation for the various sections of the staff, and a spacious and elegantly-finished club-house has also been erected on the grounds adjoining the works, with well-equipped kitchen and separate dining rooms for the staff and the workmen, whilst in connection with the club-house a bowling green is being laid out for the recreation of the employees. The site of the works is very advantageously situate both for railway and water carriage, sidings being run direct into yards and the shops from the London and North Western Railway, whilst the Stockport Canal also runs along one side.

The members having made a thorough inspection of the works, light refreshments were served, and the party proceeded to the Grand Hotel, Manchester, where they sat down to tea, Mr. E. G. Constantine, the President, occupying the chair.

During the course of the evening the President expressed his earnest hope that the members would take advantage of the offer made by Mr. Reynolds, of the Municipal School of Technology, with regard to the day training of apprentices, by arranging for their apprentices to attend the classes. He also proposed a vote of thanks for the pleasure they had received by the permission to visit the works of Messrs. Craven Bros., which had been of great interest to all the members.

Mr. W. H. S. Craven, the senior member of the firm, stated that they had been only too pleased to throw their works open to the members of the Association, and if their visit had afforded pleasure or interest they were more than satisfied.

The remainder of the evening was occupied with a programme of operatic music given by the members of the Albyn Comic Opera Company.

LIBRARY.

The Association exchanges Transactions with the following:—

American Institute of Mining Engineers.
,, Society of Mechanical Engineers.
Canadian Society of Civil Engineers.
Engine, Boiler, and Employers Liability Insurance Company.
Franklin Institute, America.
Gas Institute, Incorporated.
Institution of Civil Engineers of England.
,, Engineers and Shipbuilders in Scotland.
,, Mechanical Engineers.
Iron and Steel Institute.
Liverpool Engineering Society.
Manchester Geological Society.
,, Literary and Philosophical Society.
Midland Institute of Mining, Civil and Mechanical Engineers.
Mining Association and Institute of Cornwall.
Mining Institute of Scotland.

North of England Institute of Mining and Mechanical Engineers.
North-East Coast of Engineers and Shipbuilders.
South Wales Institute of Engineers.
Society of Engineers.

The following Publications are received periodically:—

Cassier's Magazine.
Colliery Guardian.
Fielden's Magazine.
Page's Magazine.
Engineer.
Engineering.
Iron and Steel Trades' Review.
Marine Engineer.
Mechanical World.
,, Engineer.
Practical Engineer.
Textile Mercury.
,, Recorder.
,, Manufacturer.

OBITUARY.

Henry Bates was born at Salford on 15th August, 1846. He commenced his engineering career in 1858 as an apprentice at Tammerfors, Finland. Four years later he started at Messrs. Joseph Whitworth & Co., Manchester, where he finished his apprenticeship. His subsequent experience was gained at Messrs. Smith & Coventry's Works, passing from there a few years later to Messrs. Sharp, Stewart & Co., whose works at that time were in Manchester.

He left the last-named firm in 1870 to start business on his own account, but shortly afterwards, in 1872, joined Messrs. Crossley Bros., gas-engine makers, where he remained for a few years. He next became manager of the Breech Action Manufacturing Co., Birmingham.

Some little time after this he joined the late Mr. Hulse as his chief in his business as consulting engineer at Manchester, and when that gentleman took over the Ordsal Works with the business of Messrs. Hulse & Co. in 1882, he went with him as manager.

On the reconstruction of this firm, and its transformation into a private company in 1898, he was appointed managing director, which post he filled until the time of his death. During his twenty years' connection with the works of Messrs. Hulse & Co., he was closely identified with the design and construction of the great variety of machine tools for which that firm attained a high reputation. He had also for many years occupied the position of consulting engineer and valuer to several of the largest and most important firms in the country.

His death occured at Southport on 1st February, 1903, at the age of 56. He was elected a member of the Association in 1882.

Charles O'Connor was born in Manchester in November, 1823, and was the son of Christopher O'Connor, engineer. He was educated in Manchester, and after leaving school was apprenticed to Messrs. Sharp, Roberts & Co., Faulkner Street, Manchester, machine manufacturers, but owing to the dissolution of partnership of Messrs. Sharp & Roberts, about 1840, he was turned over to Messrs. Sharp Brothers, Oxford Road, Manchester, locomotive builders, where he finished his apprenticeship in 1844.

In the year 1846 he was sent to Paris by the firm of Sharp Brothers to establish a locomotive works there at the Avenue d'Clichia, for Messrs. Ernest Gouin, where he remained about 2½ years, until after the Revolution broke out in 1848.

He then returned to Manchester, and remained with Sharp Brothers until the year 1852, when he was offered the position of crank turner, and after two years was made foreman over the

machinery department of Messrs. Beyer Peacock, Gorton, Manchester, and remained in this responsible position for 7 years.

Shortly after this he was appointed manager at the works of Messrs. Slaughter & Grunning, Avonside Engine Works, Bristol, over the turners and fitters which position he occupied 7 years.

After leaving Messrs. Slaughter & Gunning, he accepted the position of manager of the works of Messrs. Stothert & Pitt, Bath, where he was actively engaged in the necessary duties for 4½ years.

Upon relinquishing this position, he was in the year 1870 appointed working superintendent of the machinery and fitters department at Messrs. John Elder & Co., Fairfield Engine Works, Govan, Glasgow, where he remained for 9 years, and, as a mark of esteem, was presented with a very handsome clock and ornaments on his retirement from this firm to undertake the management of the machinery at Messrs. Maudsley, Son & Field, London, where he remained for a considerable time.

At this period, he was offered the position of manager of the Mersey Forge, Liverpool, where he was actively occupied in the production of several important works, amongst which might be mentioned the manufacture of the largest solid crank (in those days), for the s.s. "Servia," and also the largest iron stern-frame, weighing over 40 tons; this was for the s.s. "City of Rome." He continued in this position until the firm dissolved and the works closed.

Upon the closing of these works, and shortly afterwards, he commenced business in Liverpool on his own behalf as consulting engineer, which occupation he continued to follow. He was elected a member of the Association in 1861, and died in October, 1903.

Thomas Parker was born in Ayrshire in 1829, and served his apprenticeship with the Caledonian Railway whose works were situated in Greenock. Subsequently, for a short time, he held

an appointment with the London & North Western Railway Co., afterwards returning to the Caledonian Co. where he was principally engaged in the inspection of material and rolling stock supplied by contractors to the company. In 1860 he was appointed carriage and wagon superintendent to the Manchester, Sheffield & Lincolnshire Railway Co., and during his term of office he constructed the whole of the now existing carriage and wagon shops, and did some exceptionally notable work in connection with saloons, especially the one for the then Prince of Wales. In 1886 he was appointed locomotive engineer and carriage and wagon superintendent and designed the engine, 561, which was exhibited at the Manchester Jubilee Exhibition, this engine being of an entirely new type to those already on the line. He was the first to use Belpaire Fire-boxes extensively in this country. He retired in 1893 after a railway career of nearly 50 years, and died on the 25th November, at his residence, Gorton. He was elected a member of the Association in 1883.

Edward Mercer joined the Association in 1873. Originally he was employed as a leading turner at the works of Messrs. Routledge & Ommaney, Adelphi, Salford, and on leaving this firm many years ago he started in business on his own account, making taps, bright bolts and nuts, subsequently removing to Hollinwood, when he was engaged in the same business for the past 25 years. He was elected a member in 1873.

He died at Southport on the 9th December in his 70th year, and was interred at Hollinwood Cemetery.

Matthew Swain was elected a Member of the Association in 1877, and for many years was connected with the Railway Foundry, Newton Heath.

He died suddenly at his Buxton residence, on the 5th August, and was interred at Burbage, Buxton.

JAMES WALTHEW.—By the death of James Walthew the Association has lost one of its most valued members, and one, who, unremittingly for several decades worked sedulously to further the interests and objects of the Association in which, throughout all these years he maintained a continued and vivid interest in whatever office he was officially called upon to fill. He joined the Association in its very earliest days, about 1856, when he was appointed Secretary and continued in this position until 1874. In this year in consequence of the pressure of business responsibilities, at the works of Messrs. W. & J. Galloway & Sons, he resigned the Secretaryship and the members evinced their high appreciation of his services by presenting him with a gold watch and other tangible indications of esteem, and at the same time elected him a member. Thereafter he served on various Committees until the year 1879 when he was elected President, a position which he filled with dignity to himself and honour to the Assotiation. Subsequently he held the position of Trustee for a number of years and finally the office of Treasurer, which he retained at the time of his death.

In the course of his long connection with the Association, he made many life long friends, his disposition being so peculiarly sympathetic, there were very few with whom he ever came in contact who were not impressed with his high-mindedness and probity, and his earnest efforts to be of use to those around him; consequently he was the recipient of many confidences from members who sought his advice and assistance in times of trouble as they could always rely that whatever transpired would never be divulged to other than those concerned. Probably these prominent characteristics of Mr. Walthew could have no more striking confirmation than that evinced in his appointment as co-executor by his old and valued friend, Mr. Manassah Gledhill, who joined the Association in its early days. Mr. Gledhill, it may be remembered, left the greater portion of

his considerable fortune to be distributed to charities, as the executors might deem most desirable, and practically the very latest of the executors gifts is the magnificent new wing which has been added to the Warehousemen and Clerks School at Cheadle Hulme.

Apart from the Association, Mr. Walthew was connected with many other important organisations, being a member of the Stretford Urban Council, a chairman of the Overseers of the parish of Stretford, and a director of the Stretford Gas Co.

In addition to these important appointments, Mr. Walthew was an energetic worker in many other directions, having been associated with the St. Peter's Sunday School for upwards of 60 years.

It is a tribute to Mr. Walthew's shrewdness and common sense, that there were few organisations with which he became connected that his qualities were not invariably recognised by his being placed on the consultative boards and committees.

In the work of the Association he took exceptional interest, rarely missing the council and other meetings, where his presence was always welcomed, the quiet unostentatious way in which he gave his views on the questions submitted being always acceptable, and in many instances, desired by the council.

He died on the 16th of December, in the 73rd year of his age, at his residence, Sunny Side, Old Trafford.

The interment took place at Stretford Cemetery amidst an extraordinary manifestation of sympathy from the many public bodies with which he had been associated, and which included representatives from the Association.

TREASURERS GENERAL CASH ACCOUNT, for the Year ending 31st December, 1903.

Dr. (Including Superannuation Fund Account.) **Cr.**

1903.			£	s.	d.
Jan. 1.	To	Balance as per last Report	5,404	4	4
to	,,	Contributions and Entrance Fees	828	16	6
Dec. 31.	,,	Interest from Mortgages on Properties £181 1 6			
	,,	,, Leeds Corporation 3½% Stock..... 10 0 5			
	,,	,, Manchester Corporation 3½% Loan 11 18 10			
	,,	,, Bank 6 18 6			
			159	14	3
			£6,392	15	1

1903.			£	s.	d.
Jan. 1.	By	Rent—Grand Hotel	20	0	0
to	,,	Secretary's Salary £65 0 0			
Dec. 31.	,,	Librarian's ,, ... 10 0 0			
			75		
	,,	Superannuation Allowance.....	153	4	0
	,,	Printing and Lithography of Transactions £291 18 6			
	,,	Binding of do. 24 10 0			
	,,	Member's Lists..... 19 10 0			
	,,	General Circulars and Miscellaneous Work..... 31 4 0			
	,,	Stationery 8 11 8			
			375	13	9
	,,	Delivery of Transactions	7	13	7
	,,	Annual Dinner Expenses.....	7	4	0
	,,	Expenses *re* Mr. Amos' paper	5	0	0
	,,	Yost Typewriter	17	7	0
	,,	Library Insurance Premium.....	0	6	0
	,,	Expenses Opening Meeting Session	13	19	3
	,,	Tool Steel Experiments. Honorariums :			
		Mr. G. Anderson £7 10 0			
		Mr. Dempster Smith 5 5 0			
		Mr. J. T. Hodgson 10 0 0			
		C. Coups 3 0 0			
			25	15	0
	,,	Council and Sub-Committee Expenses £13 5 3			
	,,	Postages, Circulars, and Correspondence 55 1 0			
	,,	Sundries 33 3 5			
			101	9	8
	,,	Cash invested in Properties: Mortgages.....£3,550 0 0			
	,,	,, ,, Leeds Corporation, 3½% Stock.. 600 0 0			
	,,	,, ,, Premium on do..... 90 6 6			
	,,	,, ,, Man'ter Corpor'tion, 3½% Loan 700 0 0			
			4,940	6	6
	,,	Cash in Bank £572 7 5			
	,,	,, Treasurer's hands 55 14 2			
	,,	,, Secretary's ,, ... 21 14 9			
			649	16	4
			£6,392	15	1

Audited and found correct,

E. MARSHALL,
W. H. COOK, } AUDITORS.

27th January, 1904.

N.B.—The above Account shows a surplus on the year's working of £185. 18s. 6d.

SUPERANNUATION FUND ACCOUNT, for Year ending 31st December, 1903.

Dr. (Included in General Account. **Cr.**

1903.		£ s. d.	1903.		£ s. d.	£ s. d.
Jan. 1.	To Capital invested as per Rule passed December, 1901	5,000 0 0	Jan. 1 to Dec. 31.	By Superannuation Allowances :—		
	,, Balance from last Report	20 12 8		Mr. John R. Wolstenholme	20 16 0	
Dec. 31.	,, Twelve Month's Interest on above Capital Invested as per Rule	159 14 3		,, Jas. Glennie	11 12 0	
				,, John Dutton	20 16 0	
				,, C. O'Connor	16 16 0	
				,, J. G. Cochrane	20 16 0	
				,, J. Meller	20 16 0	
				,, J. Errock	20 16 0	
				,, R. Greenough	20 16 0	153 4 0
				,, Balance to Credit of Superannuation Fund Account		5,027 2 11
		£5,180 6 11				£5,180 6 11

Audited and found correct,

27th January, 1904.

E. MARSHALL,
W. H. COOK, } Auditors.

THE PRESIDENT'S GOLD MEDAL FUND.

Dr. **Cr.**

1903.		£	s.	d.	1903.		£	s.	d.
Dec. 31.	To Donation from the President, Mr. E. G. Constantine	150	0	0	Dec. 31.	By Cash in Bank	152	11	0
	,, Bank Interest	2	11	0					
		£152	11	0			£152	11	0

Audited and found correct,

E. MARSHALL,
W. H. COOK, } AUDITORS.

January 27th, 1904.

UNIVERSITY OF MICHIGAN
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